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Shoulder Complex Motion and Coordination Impairments, and the Associated Clinical Factors in Women with a History of Breast Cancer Treatment

A Thesis

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Abstract

Shoulder Complex Motion and Coordination Impairments, and the Associated Clinical Factors in Women with a History of Breast Cancer Treatment
Bryan A. Spinelli

Common medical management for breast cancer (BC) most often includes lumpectomy and radiation (LR) or mastectomy and reconstruction (MR). Due to these procedures involving the shoulder, it is not surprising that some women experience shoulder complex motion and coordination problems. However, the long-term effect that BC treatments have on shoulder complex motion and coordination during functional tasks is not well understood. The rationale for impaired shoulder complex motion and coordination among women with BC is that these women frequently experience impairments that are believed to contribute to these problems including soft tissue pain, decreased shoulder complex muscle strength, decreased tissue flexibility, altered resting scapular alignment (RSA), and lymphedema. However, limited research exists to support this notion. Therefore, the aims of this dissertation were 1) determine the effect that breast cancer treatments (LR and MR) have on shoulder complex motion and coordination, 2) identify clinical factors associated with impaired shoulder complex coordination in women with a history of breast cancer treatment.

Scapular and humeral kinematic data and clinical measures of pain, RSA, tissue flexibility, strength and lymphedema were collected on 30 women with BC (mean age ± SD = 53.8 ± 10.9 yrs.) and 30 women without BC (mean age ± SD = 52.7 ± 10.8 yrs.). Separate one-way multivariate analysis of variance (MANOVA) were conducted to determine whether differences in shoulder complex motion existed between groups (p <

.05). Angle-angle and relative motion graphs were created for 3 scapular and 2 clavicular rotations. Mean curves with 95% minimal detectable change bands (MDCB) were calculated using data from women without BC. Each woman with BC's curve was individually compared to the mean curve and MDCB. Women with BC were classified as having normal (curve fell within MDCB) or impaired shoulder complex coordination (curve fell outside MDCB). Discriminant analyses were used to identify clinical variables that could classify women as having normal or impaired shoulder complex coordination ($p < .05$).

There were no significant differences in shoulder complex motion between women with and without BC or between those with different medical management (LR, MR). Over 93% of women with BC demonstrated impaired shoulder complex coordination for at least 1 scapular or clavicular rotation. Discriminant analysis revealed that clinical measures of pain, RSA, tissue flexibility, strength, and lymphedema were associated with impaired shoulder complex coordination. Cross-validated classification showed that 43.4% to 73.3% of women were grouped correctly.

Failure to find group differences in motion may be due to the fact that women in our study were relatively high functioning and recovered from their medical management. Additionally, the majority of women in our study were previously educated on a home exercise program (73.3%) and attended physical therapy (56.7%). A lack of significant differences in shoulder complex motion between women with and without a BC suggests that the women in our study had sufficient range of motion to accomplish the functional tasks. Although we did not find differences in motion between women with and without BC across functional tasks, the majority women with BC

demonstrated impaired shoulder complex coordination. Clinical measures of tissue flexibility (ROM and pectoralis minor length) were associated with impaired shoulder complex coordination across multiple scapular and clavicular rotations.

CHAPTER 1: DISSERATION PROPOSAL

1A: SPECIFIC AIMS

Among the 2.6 million women who survive breast cancer in the United States an estimated 35% (750,000 women) experience shoulder pain and upper extremity functional loss. Restricted shoulder motion has been associated with these problems as well as a reduction in health related quality of life (HRQoL). Although this problem is well documented, women continue to experience restricted motion months to years after treatment. This problem is potentially because the current understanding of restricted shoulder motion is frequently limited to humerothoracic motion with little regard for a comprehensive understanding of the effect of breast cancer treatments on the amount and coordination of shoulder complex (humerus, scapula, and clavicle) motion. Furthermore, the effect that surgical procedures and radiation therapies have on musculoskeletal structures of the shoulder complex and whether these effects are associated with impaired motion and coordination is poorly understood. These gaps limit the ability of rehabilitation specialists to provide optimal care following surgical interventions and radiation therapies for women undergoing breast cancer treatment.

The long-term goal of this research is to reduce shoulder complex impairments, associated activity limitations, and participation restrictions amongst breast cancer survivors. The objective of the proposed research is to determine the effect that breast cancer treatment options have on shoulder complex motion, coordination, and select musculoskeletal structures. The central hypothesis is that following breast cancer treatment women will demonstrate clinical factors (pain, musculoskeletal impairments, and lymphedema) that will be associated with impaired shoulder complex coordination.

The rationale for this research is that a better understanding of shoulder complex motion and coordination impairments, and the clinical factors associated with these problems will lead to improved evidence based examination, intervention, and prevention procedures. This in turn may lead to a reduction in the prevalence of shoulder complex pain and dysfunction and improved HRQoL amongst breast cancer survivors.

I plan to achieve the objective of this proposal by pursuing the following specific aims:

1. **Determine the effect that breast cancer treatments (lumpectomy and radiation, and mastectomy with breast reconstruction) have on shoulder complex motion and coordination.**

   Working hypothesis 1a: Women with a history of surgery and radiation will demonstrate greater impairments in shoulder complex motion during functional reaching tasks when compared to women with surgery only.

   Working hypothesis 1b: Women with a history of surgery only will demonstrate impairments in shoulder complex motion during functional reaching tasks compared to women without a history of breast cancer treatment.

   Working hypothesis1c: A greater percentage of women with a history of surgery and radiation will demonstrate impaired shoulder complex coordination during functional reaching tasks compared to women with a history of surgery only.

2. **Identify clinical factors associated with impaired shoulder complex coordination in women with a history of breast cancer treatment.**

   Working hypothesis 2: Pain, decreased shoulder complex muscle strength, decreased pectoralis muscle flexibility, altered resting scapular alignment, and upper extremity lymphedema will be associated with impaired shoulder complex coordination.

The expected outcome of Specific Aim 1 will be a more thorough understanding of the effect that breast cancer treatments have on shoulder complex motion and coordination in breast cancer survivors. The expected outcome of Specific Aim 2 will be the identification of clinical factors associated with impaired shoulder complex coordination. Collectively these findings will provide health care providers with advanced understanding of shoulder complex motion and coordination impairments following curative treatment regimes. Additionally, knowledge of associated clinical factors will lead to development or refinement of clinical examination and intervention procedures that ultimately may lead to improvements in function and participation in work and leisure activities for this population.

1B: SIGNIFICANCE SUBSECTION

Approximately 200, 000 women are diagnosed with breast cancer each year in the United States.[1] The 5-year survival rate is approximately 90%[1], and currently over 2.6 million breast cancer survivors reside in the United States[1]. Increased life expectancy emphasizes the need to shift focus onto HRQoL after treatment.

Clinical stage I and II breast cancers account for approximately 60-65% of all breast cancers.[2] The National Comprehensive Cancer Network guidelines for the medical management of clinical stage I or II breast cancer is lumpectomy with axillary lymph node surgery and radiation therapy to the breast, or mastectomy with axillary lymph node surgery with or without reconstruction. These breast cancer treatments involve one or more regions of the shoulder, which places women at risk for developing shoulder complex impairments. Impaired shoulder motion is an important problem for many breast cancer survivors as it has been shown to be associated with activity limitations, participation restrictions, and reduced HRQoL.[3-8] Impaired shoulder motion has been reported to affect up to 67% of breast cancer survivors with reported motion losses ranging from 3°- 17° for flexion, 7°- 33° for abduction, 1°- 11° for external rotation, and 1°- 4° for internal rotation.[5,9-12] Although this problem is well documented[4-6,8,11-13], the majority of investigators have focused on the amount of humeral motion relative to the trunk (humerothoracic motion). However, shoulder motion involves motions of the scapular, clavicular, and humeral segments. During arm movements, coordinated motion of scapular, clavicular, and humeral segments (shoulder complex coordination) are important for maintaining alignment of the humeral head and glenoid, and size of the subacromial space.[14-16] Impaired motion and coordination may lead to excessive stresses being placed upon tissues thereby increasing the risk for development of musculoskeletal shoulder pathologies (e.g., rotator cuff disease).[17] The premise behind breast cancer survivors having impaired shoulder complex motion and coordination is based on the notion that survivors experience impairments such as pain, decreased shoulder complex muscle strength, decreased tissue flexibility, altered resting scapular alignment, and lymphedema secondary to the effect breast treatments (surgery and radiation) have on the anatomical structures related to the shoulder complex.[12,18-20] The contribution of the proposed research is expected to determine whether women after breast cancer treatment demonstrate shoulder complex motion and coordination impairments, and identify the prominent clinical factors associated with these problems in breast cancer survivors. This advancement in knowledge will highlight impairments to be screened for and addressed by rehabilitation professionals in order to restore typical shoulder function. Both are important steps towards reducing the risk for developing musculoskeletal shoulder pathologies, reducing disability, and maximizing HRQoL.

1C: INNOVATION SUBSECTION

Many breast cancer survivors experience activity limitations that are dependent upon shoulder motion including combing hair, dressing, and reaching overhead.[4] In previous studies where the segmental contributions of shoulder motion in women with a history of breast cancer treatment has been investigated, motion was assessed while women performed constrained arm movements. Functional activities that require shoulder motion typically are not performed under constrained conditions, and recent research has shown that scapular motion differs between constrained and unconstrained tasks.[21] My proposed research plan is to investigate segmental contributions of shoulder motion during functional activities that have been commonly reported to be limited in women with a history of breast cancer treatment.

Additionally, previous investigators analyzed the amount of scapular motion at select humeral angles. This approach does not completely capture shoulder complex coordination that is essential for positioning the hand in space to perform various daily and recreational activities. My proposed research is innovative because the analyses used in this study will focus on evaluation of continuous patterns of shoulder complex coordination. These analyses provide essential information beyond the amount of scapular motion, and describe the relationship between multiple segments during arm movements. This approach will improve our understanding of shoulder complex coordination in women after breast cancer treatment.

1D: BACKGROUND

Shoulder motion is essential for positioning the hand in space in order to perform many activities of daily living that involve the upper extremity. Impaired shoulder motion has been reported to affect up to 67% of breast cancer survivors with reported motion losses ranging from 3°- 17° for flexion, 7°- 33° for abduction, 1°- 11° for external rotation, and 1°- 4° for internal rotation.[5,9-12] Although impaired shoulder motion following breast cancer treatment is well documented[4-6,8,11-13], breast cancer survivors continue to experience motion impairments years after treatment.[4,22] This long-term complication may be because women failing to discuss their shoulder problems with health care providers,[8] lack of referrals for women who may benefit from rehabilitation services,[23] or ineffective screening and rehabilitation interventions because of a poor understanding of the mechanisms associated with impaired shoulder motion. Additionally, the majority of investigators have focused on traditional measures of shoulder motion. These motions represent the range of motion that the humerus moves with respect to the trunk (humerothoracic motion). Daily activities require motion of multiple bony segments of the shoulder complex including the humerus, scapula and clavicle. The combined motion of glenohumeral, scapulothoracic, acromioclavicular, and sternoclavicular joints is necessary for typical shoulder complex motion and function. Impaired glenohumeral and scapulothoracic motion have been theorized to be causative factors for developing musculoskeletal related shoulder pathologies including symptomatic rotator cuff disease. [15]

Symptomatic rotator cuff disease has been suggested to be a significant cause of shoulder pain in women following breast cancer treatment and has been reported to be the second most common upper limb health condition in woman behind lymphedema.[20,24,25] The12-month post-treatment prevalence of rotator cuff disease has been reported as 7.1%.[20]

The etiology of rotator cuff disease is multi-factorial with proposed mechanistic theories suggesting intrinsic and extrinsic factors. Intrinsic factors refer to degeneration within the tendon owing to aging, avascularity, macro-trauma, repetitive micro-trauma, and tension overload.[26-28] Extrinsic factors refer to mechanical compression of subacromial tissues caused by structure(s) outside of the rotator cuff tendon(s)[28,29], and include impaired shoulder complex motion[16].

During arm motions, the contributions of glenohumeral and scapulothoracic motion are believed to influence alignment between the humeral head and glenoid fossa, as well as the size of the subacromial space.[14-16] Impaired glenohumeral and scapulothoracic motion may lead to excessive stresses being placed upon tissues thereby increasing the risk for development of symptomatic rotator cuff disease.[17] A better understanding of these motions may provide evidence to explain why symptomatic rotator cuff is a significant problem affecting breast cancer survivors, and highlight impairments to be screened for and addressed by rehabilitation professionals to reduce risk for developing symptomatic rotator cuff disease.

Limited information exists relative to understanding the effects of breast cancer treatments on segmental motions of the shoulder complex. Three investigative groups have conducted research on scapulothoracic motion in women with a history of breast cancer.[30-32] Shamley et al.[32] compared scapulothoracic motion between the involved and uninvolved sides of 152 breast cancer survivors. Subjects were treated with a variety of medical interventions including surgery (breast conserving or mastectomy), radiation (no radiation, radiation to chest wall, or radiation to chest wall and axilla), and chemotherapy (yes or no). Surgeries were performed, on average, 3.1 years prior to participation in the study. Bilateral, three-dimensional scapulothoracic motion was collected during overhead scapular plane arm elevation. Impaired scapulothoracic motion was reported on the affected side, and the authors noted that the direction of alterations differed based on which side was affected.

Crosbie et al.[31] compared scapulothoracic motion between the affected and unaffected sides in women with and without a history of breast cancer. Fifty-three women who had a unilateral mastectomy at least one year prior to participation in the study were age matched with 22 women without a history of breast cancer. Women in both groups had no history of upper limb or spine problems, and women in the breast cancer group did not have lymphedema. Bilateral three-dimensional scapulothoracic motion was collected during seated trials of overhead arm motion in the sagittal, scapular, and frontal planes. Although subjects were required to have at least 150° of shoulder flexion motion and were instructed to raise their arm overhead as far as they could, the authors only reported scapulothoracic motion up to 90° of humeral elevation. As a group, women with breast cancer demonstrated significantly greater scapular upward rotation during scapular and frontal plane arm elevation compared to women without breast cancer. Other scapulothoracic motion impairments were found; however, the type of motion alteration differed based on whether the dominant side or non-dominant side was affected.

Finally, Borstad and Szucs[30] investigated the effect of breast cancer surgery on scapulothoracic motion. Eleven subjects (10 women, 1 male) who were scheduled for unilateral breast cancer surgery participated in the study. All subjects had no shoulder pain prior to surgery, or history of previous shoulder surgery. Scapulothoracic motion was collected pre-surgery and 2 months post-surgery during standing trials of scapular plane arm elevation. Post-surgery, subjects demonstrated increased scapular internal rotation and increased anterior tilt during arm elevation.

While these studies provide preliminary evidence that indicates impaired scapulothoracic motion exists in breast cancer survivors, further studies are needed to overcome the limitations of these studies and expand our understanding of this problem. The primary limitations of these previously mentioned studies include: measurement of scapulothoracic motion during constrained tasks and analysis of scapulothoracic motion at select humeral angles.

Scapulothoracic motions were measured while women raised and lowered their arm through a specified plane of motion. Functional activities that require shoulder motion are not typically constrained to a specified plane of motion. Recent evidence has shown that scapulothoracic motion differs between constrained and unconstrained tasks.[21] Furthermore, in these studies the amount of scapulothoracic motion was analyzed at select humeral angles, which does not completely capture the coordinated motion between the scapula or clavicle and humerus (shoulder complex coordination) throughout the movement cycle. Daily and recreational activities that involve overhead arm movements require continuous shoulder complex coordination. Whether breast cancer survivors demonstrate impaired shoulder complex motion or coordination during functional tasks has not been investigated. Determining this is important because many breast survivors experience activity limitations that are dependent upon shoulder complex motion and coordination.[4]

The rationale for impaired shoulder complex motion and coordination among breast cancer survivors is that these women frequently experience impairments that are believed to contribute to these problems including soft tissue pain, decreased shoulder complex muscle strength, decreased tissue flexibility, altered resting scapular alignment, and lymphedema. This is not surprising owing to the affect breast cancer treatments (surgery and radiation) have on the anatomical structures of one or more shoulder complex regions (pectoral or axillary).

The prevalence of shoulder and/or arm pain ranges from 9-68%, and the prevalence of breast/scar pain ranges from 15-72% at 6-56 months after surgery.[12] Women experience soft tissue pain after surgery secondary to tissue injury, which may result from surgical incisions or muscle injury.[33] Pectoralis muscle injury may occur after reflection during axillary node dissection or after the pectoralis major is used to create a submuscular pouch for tissue expander placement during non-autologous breast reconstruction.[33] Pain may cause muscle inhibition or lead to compensatory movement strategies in order to reduce symptoms during motion.

Twenty-two muscles at the shoulder complex contribute to the production of motion and coordination. Women may present with muscle performance impairments that contribute to impaired shoulder complex motion and coordination such as altered muscle activity[34], muscle atrophy[34,35], and decreased muscle strength[10,11,18,36-38] During axillary node dissection, structures of the nervous system such as the long thoracic nerve, thoracodorsal nerve, and medial and lateral pectoral nerves are located in the surgical field.[39] Impairment to these nerves may result in atrophy of the innervated muscles and lead to muscle performance impairments.[35]

The rationale for altered resting scapular alignment contributing to impaired shoulder complex motion and coordination is based on the belief that altered resting scapular alignment results in structural changes to the musculoskeletal tissues associated with the shoulder complex.[40] These changes are presumed to affect the active and passive forces acting at the shoulder complex resulting in altered shoulder complex motion and coordination during arm movements [17,41]. Women may demonstrate altered resting alignment secondary to protective posturing in order to modulate pain and protect surgical sites.[42] To the best of our knowledge, only one investigative group has compared resting alignment between women with and without a history of breast cancer [19]. In this study, Moire topography was used to perform a photogrammetric assessment of resting scapular alignment. The findings from this study revealed that breast cancer survivors demonstrated altered resting alignment of their affected and unaffected shoulders when compared to age matched women without breast cancer [19]. Visual assessment of resting scapular alignment is component of routine shoulder examinations performed by rehabilitation professionals who manage musculoskeletal impairments in breast cancer survivors. However, whether breast cancer survivors demonstrate differences in visual resting scapular alignment compared to woman without a history of breast cancer is unknown.

Breast cancer survivors may experience decreased pectoralis major and minor muscle flexibility owing to limiting arm motion secondary to pain or fear of complications. Pectoralis major and minor muscle flexibility may be further complicated by the previously mentioned protective posturing.[42] Additionally, radiation therapy has been shown to alter collagen synthesis[43-45], and cause soft tissue fibrosis affecting the flexibility of tissues within the radiation field[44-46]. Yang et al.[20] assessed pectoralis flexibility in women at 3 time points following surgery for breast cancer. Decreased pectoralis flexibility was defined as the presence of limited passive forward flexion and horizontal abduction by more than 10 degrees, with no limited passive external rotation.[20] Prevalence rates for decreased pectoralis flexibility were reported as 8.9%, 12.3%, and 8.7% at 3, 6, and 12 months respectively.[20] However, it was not clear whether the definition of decreased pectoralis flexibility using limited passive range of motion was in reference to the unaffected side or a normative value. Whether breast cancer survivors demonstrate decreased pectoralis minor flexibility has not been systematically determined. The pectoralis minor elongates during arm elevation.[47] Although a short resting pectoralis minor muscle length has been shown to impair scapulothoracic motion [48], the relationship between pectoralis minor flexibility and impaired shoulder complex motion and coordination has not been investigated in women with a history of breast cancer treatment.

Upper extremity lymphedema has been reported to affect up to 70% of women with a history of breast cancer treatment [49-51]. The risk of women developing lymphedema is increased after mastectomy compared to lumpectomy, axillary lymph node dissection compared with no axillary dissection, axillary lymph node dissection compared to sentinel node biopsy, and radiation therapy.[52] Secondary to an abnormal accumulation of fluid, upper extremity limb volume and weight on the involved side may be increased [42]. An increased limb weight would theoretically place greater demand on the shoulder complex muscles, which may in turn impact shoulder complex motion and coordination.

Although women with a history of breast cancer treatment have been shown to experience a number of these factors, their association with impaired shoulder complex motion and coordination has yet to be supported. Rehabilitation professionals do not directly address shoulder complex motion and coordination impairments, but attempt to address the mechanisms that are believed to be contributing factors. A better understanding of shoulder complex motion and coordination impairments and the underling mechanisms associated with motion and coordination impairments will lead to evidence based examination, intervention, and prevention techniques designed to maximize functional ability and reduce the risk for developing musculoskeletal related shoulder pathologies in women who have been treated for breast cancer.

1E: PRELIMINARY WORK

Study 1: The Reliability of Measuring Shoulder Complex Motion Patterns and Range of Motion and Establishment of Minimal Detectable Change Bands for Classifying Movement Patterns

Nineteen individuals (13 females; 24.5 +/- 3.9 years; 9 dominant side tested) without a current episode of shoulder pain participated in a pilot study to investigate the reliability of our shoulder complex kinematic measurement procedures and establish minimal detectable change bands (MDCB) for classifying movement patterns. The Liberty™ (Polhemus, Colchester, Vermont) was used to collect 3D kinematic data from the humerus, scapula, and trunk during sagittal and frontal plane arm elevation as well an overhead reaching task during 2 testing sessions a week apart.

Study 1a: Repeatability of Scapular and Humeral Segmental Motion Patterns

Trial to trial and between day repeatability of scapular and humeral motion patterns during frontal and sagittal plane arm elevation were determined by calculating the coefficient of multiple correlation (CMC).[53] Trial to trial and between day CMC values for scapular and humeral motion patterns ranged from .82 to .99, and .54 to .98, respectively.[54] Overall these values indicate moderate to excellent reliability and indicate that the measurement of continuous scapular and humeral motion patterns are consistent between trials and days.

Study 1b: Reliability and Measurement Error of Scapular, Clavicular, and Humeral Range of Motion

Intra-class correlation coefficients (ICC $_{(3, 3)}$), standard error of the measurement (SEM), and minimal detectable change 95% ($MDC_{95\%}$) values for scapular, clavicular, and humeral range of motion were determined from an overhead-reaching task. ICCs $_{(3,3)}$, SEMs, $MDC_{95\%}$ values for scapular, clavicular, and humeral range of motion can be found in Table 1. 0verall these values represent moderate to excellent reliability and indicate that these measures are consistent between days. These results are consistent with other investigators who reported the error associated with kinematic measurement.[55,56]

Table 1: Intraclass correlation coefficient ($ICC_{(3, 3)}$), standard error of measurement (SEM) and minimal detectable change ($MDC_{95\%}$) values for scapular, clavicular and humeral range of motion during un-weighted overhead reaching

Rotation (range of motion)	**$ICC_{(3, 3)}$**	**SEM**	**$MDC_{95\%}$**
Scapular Internal Rotation	.88	1.6-2.4°	4.3-6.6°
Scapular Upward Rotation	.90	1.5-1.7°	4.2-4.6°
Scapular Anterior Tilt	.91	1.4-1.6°	3.9-4.4°
Clavicular Elevation	.71	1.8-2.1°	5.0-5.7°
Clavicular Protraction	.88	1.8-2.3°	5.1-6.3°
Glenohumeral Elevation	.77	2.1-2.6°	5.7-7.2°
Glenohumeral Adduction	.87	2.6-3.1°	7.4-8.6°
Glenohumeral Internal Rotation	.79	2.7-3.3°	9.1-11.4°
Humerothoracic Elevation	.91	2.7-4.1°	5.6-7.6°

Study 1c: Development of Minimal Detectable Change Bands to Assess Shoulder Complex Coordination

Three independent examiners with over five years of clinical experience rated scapular motion as typical (normal) or aberrant (subtle or obvious) by viewing individuals from behind during five repetitions of bilateral sagittal plane arm elevation as described by McClure et al. 2009. Final rating of each individual's motion was based on the majority rating amongst the three examiners. For example if examiner 1 rated individual as normal, examiner 2 rated individual as aberrant and examiner 3 rated individual as normal, the final rating for the individual would be normal. The Liberty™ was then used to collect 3D kinematic data as individuals repeated the elevation task. Kinematic data were resampled to 101 data points for each trial using a LabView program. Averaged angle-angle graphs with 95% minimal detectable change bands ($MDCB_{95\%}$) were created from data of individuals who were visually rated as having typical motion (n = 9). Averaged angle-angle graphs were created using kinematic data from trials 2-4 with humerothoracic elevation on the X-axis and each scapular and clavicular rotation on the Y-axis. Intraclass correlation coefficients ($ICC_{(3,3)}$) were calculated for all scapular and clavicular rotations at each of the 101 data points based on data collected between days. SEMs were calculated as follows: SEM = standard deviation (1-$ICC_{(3,3)}$). MDCBs were calculated as follows: $MDCB_{95}$ = mean +/- 1.96 x standard error of the measure (SEM) x $\sqrt{2}$. Scapular and clavicular motions from individuals (n = 10) who were rated as having visual aberrant motion were compared to these angle-angle graphs. All graphs were divided into four phases of the total movement: 0%-24%, 25%-50%, 51%-75%, and 76%-100%. Individuals were considered to have impaired shoulder complex coordination if a rotation lied outside the $MDCB_{95}$ for at least 2 of the 4 phases, or at least 2 rotations fell outside the $MDCB_{95}$ for at least 1 phase.

An example of an individual with visually rated as having aberrant scapular motion and the differences in shoulder complex coordination compared to individuals visually rated as having typical scapular motion is illustrated in Figure 1. The results of this work support the use of $MDCB_{95}$ for detecting impaired shoulder complex coordination using kinematic data.[57]

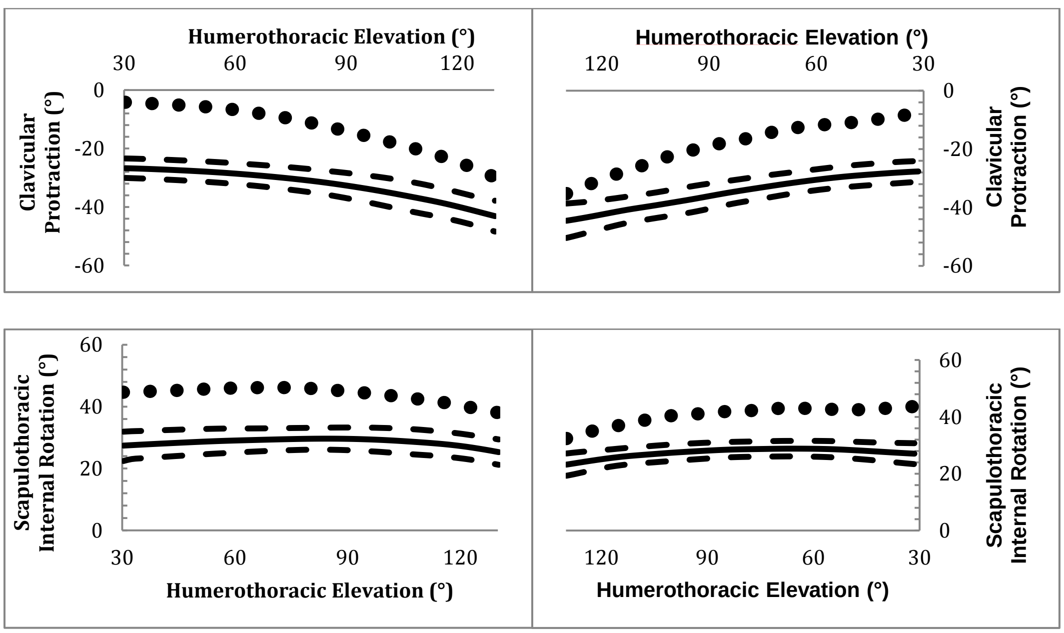

Figure 1: Angle-angle graphs. Mean of subjects visually rated as having ideal scapular motion (solid black) & +/- minimal detectable change bands ($MDCB_{95}$) (dashed black). Single subject with visually rated as having aberrant scapular motion (circle black).

Study 2: Shoulder Complex Coordination and Musculoskeletal Impairments in Women after Breast Cancer Treatment

Five women (mean age +/- SD = 59.6 +/- 7.3 years) with a history of breast cancer treatment and 1 woman (56 years of age) without a history of breast cancer treatment participated in this pilot study. Descriptive data can be found in Table 2.

The primary author who has 11 years of clinical experience performed a series of clinical measures typically collected as part of a standard physical therapy examination of the shoulder complex. These measures consisted of: self-report of pain during arm motion and musculoskeletal assessments of the shoulder complex. A numeric pain rating scale (0 = no pain, 10 = worst imaginable pain) was used to assess pain during arm motion. A universal goniometer was used to measure passive shoulder forward elevation and external rotation at 90 degrees abduction range of motion. The PALpation Meter (PALM) (Performance Attainment Associates, St. Paul, Minnesota) was used to measure resting and elongated pectoralis minor length in order to assess pectoralis minor flexibility. Shoulder forward elevation, external rotation, and internal rotation strength was measured using a hand held dynamometer (Lafayette Instrument Company, Lafayette, Indiana). A visual assessment of resting scapular alignment was performed. Clinical data can be found in table 3.

The Liberty^{TM} (Polhemus, Colchester, Vermont) was used to collect 3D kinematic data from the humerus, scapula, and trunk during 5 trials of an overhead reaching task. Averaged angle-angle graphs were created using kinematic data from trials 2-4 with humerothoracic elevation on the X-axis and each scapular and clavicular rotation on the Y-axis. Averaged angle-angle graphs were created from data of the woman without a history of breast cancer with 95% minimal detectable change bands ($MDCB_{95\%}$) calculated from study 1c. Each averaged angle-angle graph of woman with a history of breast cancer was individually compared to the angle-angle graphs with $MDCB_{95\%}$of the woman without a history of breast cancer. An example of a woman (60 years of age) with a history of breast cancer treatment and the differences in coordination of the shoulder complex compared to a woman (56 years of age) without a history of breast cancer matched by age (+/- 5 years of age) and hand dominance (preferred hand for performing tasks) is illustrated in Figure 2.

The results of this pilot study demonstrate the feasibility of collecting the measures related to the aims of this proposal. There were no adverse events that occurred as a result of testing.

Table 2: Subject descriptive data

	Age (yrs.)	Side Affected/ Tested	Breast Surgery	Lymph node surgery	Radiation
BrCa_1	48	D	BCS	ALND	Yes
BrCa_2	60	D	BCS	SLNB	Yes
BrCa_3	68	D	BCS	ALND	Yes
BrCa_4	60	ND	BCS	SLNB	Yes
BrCa_5	62	ND	BCS	SLNB	Yes
Control_1	56	ND			

D: dominant side; ND: non-dominant side; BCS: breast conserving surgery; ALND: axillary lymph node dissection; SLNB: sentinel lymph node biopsy

Table 3: Clinical data from the involved sides of women with a history of breast cancer (n = 5) and non-dominant side of woman without a history of breast cancer (n = 1)

	Pain during arm motion	PROM Forward Elevation (°)	PROM ER at 90° ABD (°)	Pectoralis minor flexibility^	Forward Elevation Force (kg)	IR Force (kg)	ER Force (kg)	Resting Scapular Alignment*
BrCa_1	0/10	154	95	10.3	10.0	7.1	6.4	Typical
BrCa_2	5/10	138	80	17.8	4.5	4.1	1.8	Obvious
BrCa_3	6/10	135	68	7.5	3.4	2.7	3.1	Obvious
BrCa_4	1.5/10	158	75	0.6	9.0	8.6	6.2	Subtle
BrCa_5	9/10	160	70	9.5	6.2	8.4	8.5	Typical
Control_1	0/10	170	90	16.2	11.7	10.5	6.6	Typical

PROM: passive range of motion; ER: external rotation; ABD: abduction; IR: internal rotation;
^ : pectoralis minor flexibility = ((pectoralis minor elongated length/clavicle length) – (pectoralis minor resting length/clavical length))* 100;
* : rating scale (typical, subtle, obvious)

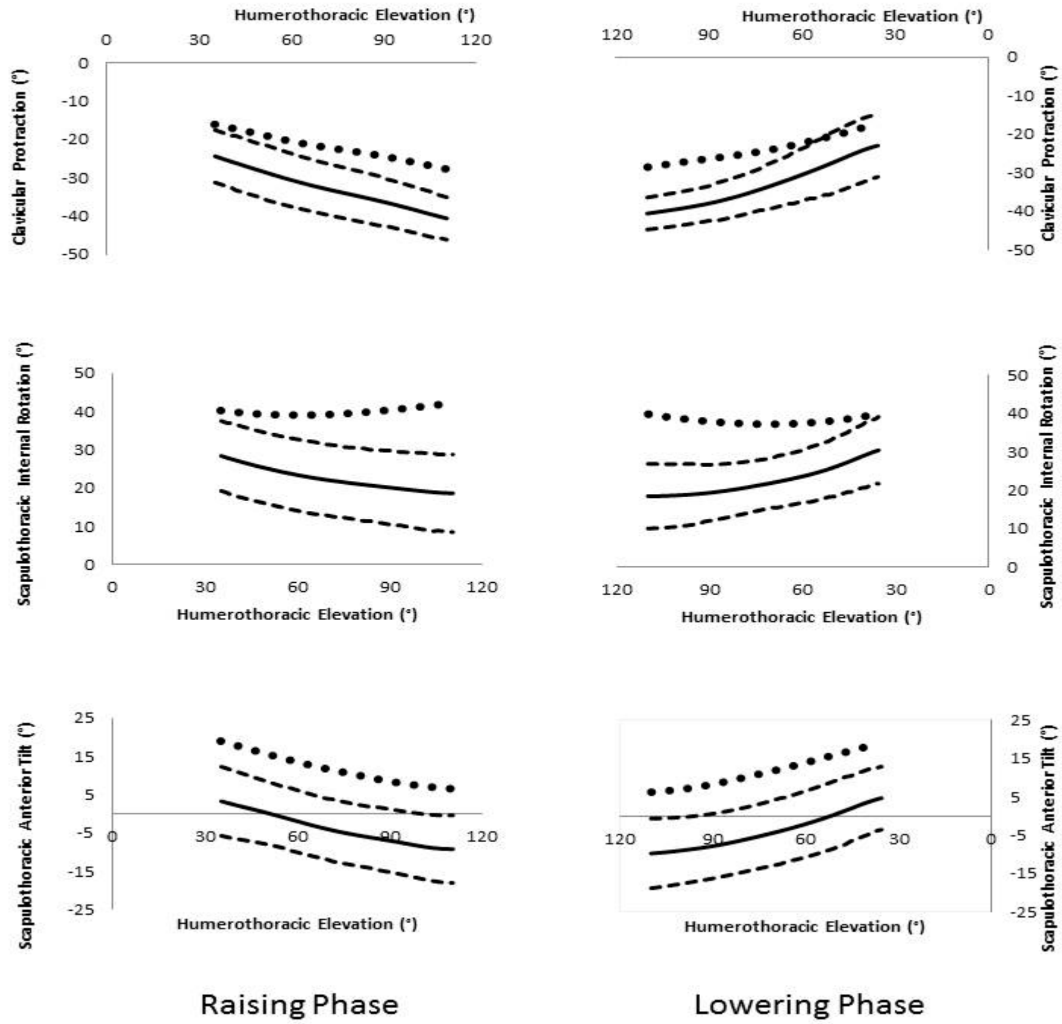

Figure 2: Averaged angle-angle graphs of subject Control_ 1 (woman without a history of breast cancer) (solid black), +/- minimal detectable change bands ($MDCB_{95\%}$) from previous pilot study (dashed black), and averaged angle-angle graphs of subject BrCa_4 (woman with history of breast cancer) (circles black). Note the pattern of Brca_4 falls outside the $MDCB_{95\%}$ indicating we can be 95% confident that the difference in her pattern is beyond our measurement error

1F: RESEARCH DESIGN AND METHODS

a. Research Design

One study using a cross sectional design will test the two specific aims.

b. Subjects/Participants

A sample of convenience will be obtained from the greater Philadelphia area through the use of flyers, advertisement in local media, and personal contact. Seventy-five female participants (50 with a history of breast cancer treatment and 25 controls) will be recruited. An equal number of breast cancer survivors treated with lumpectomy and radiation (n = 25), and mastectomy with immediate breast reconstruction (n = 25) will be recruited. Inclusion and exclusion criteria can be found in Table 4.

Table 4: Study participant inclusion and exclusion criteria.

	Lumpectomy and radiation group	**Mastectomy with reconstruction group**	**Controls**
Inclusion criteria	Age 30-70 years	Age 30-70 years	Age 30-70 years
	Unilateral breast cancer	Unilateral breast cancer	
	History of lumpectomy	History of mastectomy with immediate breast reconstruction	
	History of sentinel lymph node biopsy or axillary lymph node dissection	History of sentinel lymph node biopsy or axillary lymph node dissection	
	One to 3 years after surgery	One to 3 years after surgery	
	History of breast radiation		
Exclusion criteria	Inability to reach overhead	Inability to reach overhead	Inability to reach overhead
	Allergy to adhesive materials	Allergy to adhesive materials	Allergy to adhesive materials
	History of neuromuscular condition (ie CVA, cervical myopathy)	History of neuromuscular condition (ie CVA, cervical myopathy)	History of neuromuscular condition (ie CVA, cervical myopathy)
	History of shoulder musculoskeletal condition requiring medical intervention prior to breast cancer diagnosis	History of shoulder musculoskeletal condition requiring medical intervention prior to breast cancer diagnosis	History of shoulder musculoskeletal condition requiring medical intervention
	History of partial breast radiation or brachytherapy	History of latissimus dorsi flap reconstruction	History of breast cancer
		Surgery within previous 3 months (ie breast revision, nipple reconstruction)	
		History of radiation	

We will strive for equal numbers of women across 4 age brackets (30-39 yrs., 40-49 yrs., 50-59 yrs., 60-70 yrs.) between groups. This will be achieved by initially delaying recruiting control participants.

Sample Size / Power Analysis

Aim 1a and 1b:

An a-priori power analysis using GPower 3.1 revealed a total sample size of 67 subjects would be needed to achieve power equal to 0.80 and alpha equal to 0.05 for 3 groups with 8 measurements (scapular, clavicular, and humeral range of motion) anticipating a 5° difference between groups with a standard deviation of 15° and a correlation of 0.40 among variables. A 5° difference between groups was based on the amount needed to exceed our standard error of measurement for range of motion during overhead reaching.

Aim 1c and 2:

Because the proportion of breast cancer survivors with impaired shoulder complex coordination and the associated clinical factors are unknown, a-prior power analysis was not conducted. These aims are exploratory and results of these aims could be used to power any future studies.

Recruitment

Approximately 10 breast cancer survivors are evaluated for physical therapy services per month at Good Shepherd PENN Partners (GSPP). A meeting will be scheduled to present research proposal to therapists at Good Shepherd PENN Partners. Therapists at Good Shepherd PENN Partners will inform potential subjects of this study. Interested individuals will be issued the contact information for researchers at Drexel University, and instructed to contact the researchers at Drexel University. An appointment will be scheduled to obtain informed consent and participate in data collection.

A breast cancer surgeon affiliated with Hahnemann Hospital and Drexel Medicine, who is a dissertation committee member, currently sees approximately 80 new breast cancer cases per year. This surgeon will be shadowed each week. Potential subjects will be informed of the study. Interested individuals will be issued the contact information for researchers at Drexel University, and instructed to contact the researchers at Drexel University. An appointment will be scheduled to obtain informed consent and participate in data collection.

c. Clinical Measures and Instrumentation

Clinical Shoulder Measures

A series of clinical measures typically collected as part of a standard physical therapy examination of the shoulder complex will be performed. These measures include: self-report questionnaires, musculoskeletal assessments, and lymphedema assessment. Musculoskeletal assessments and lymphedema assessment will be performed by the primary author who has 11 years of clinical experience.

Self-report questionnaires

Subjects will complete a self-report questions relating to pain intensity, shoulder pain and disability, fear of physical activity and/or exercise, and health related quality of life (Appendix D).

Pain Intensity: Pain at rest and during arm motion will be determined using the 11-point Numeric Pain Rating Scale (0 = “no pain”, 10 = “most imaginable pain”).[58]

Shoulder Pain and Disability: The PENN Shoulder Score is a self-report measure based on a 100-point scale that consists of three-subscales: pain, satisfaction, and function.[59] The pain subscale is based on 30 points, where subjects rate their level of pain at rest, with normal activities, and with strenuous activities using an 11-point numeric rating scale.[59] The satisfaction subscale is assessed using an 11-point numeric rating scale, where 0 = “non satisfied” and 10 = “very satisfied.”[59] The function subscale is based on the sum of 20 items, using a 4-point Likert Scale (0 = “can’t do at all”, 1 = “much difficulty”, 2 = “with some difficulty”, and 3 = “no difficulty”).[59] Lower scores indicate greater pain and disability. [59]

Fear of Physical Activity: The Fear of Physical Activity/Exercise Scale-Breast Cancer (FPAX-B) is a self-report measure based on a 92-point scale that covers 7 constructs: side effects/symptoms, overall health, pain/injury, lymphedema, body image, recurrence, lack of knowledge/misinformation.[60] It is based on the sum of 23 items, using a 5-point Likert Scale (0 = “Not at all”, 1 = “A little bit”, 2 = “Somewhat”, 3 = “Quite a bit”, and 4 = “Very much”). [60] Higher scores indicate more fear of physical activity or exercise. [60]

Health Related Quality of Life: The Functional Assessment of Cancer Therapy-Breast Cancer + 4 (FACT-B+4) is a self-report measure based on a 144-point scale that includes the Functional Assessment of Cancer Therapy-General (FACT-G), breast-cancer subscale, and arm-subscale.[61,62] The FACT-G is a multi-dimensional scale that includes the following domains: physical well-being, social well-being, emotional well-being, and functional well-being.[61,62] The breast-cancer subscale (9 questions) and arm subscale (5 questions) relate specifically to women with history of breast cancer treatment.[61,62] Lower scores indicate reduced quality of life.[61,62]

<u>Musculoskeletal Assessments</u>

The primary author who is a physical therapist with 11 years of expertise in examination of the shoulder and treatment of breast cancer survivors will perform the following tests and measures.

Shoulder Strength: Bilateral isometric shoulder force production will be measured using a hand-held dynamometer. The following measures will be obtained: external rotation force at 0 degrees abduction with neutral internal/external rotation, internal rotation force at 0 degrees abduction with neutral internal/external rotation, and forward elevation in the plane of the scapular at 45 degrees of elevation. For these tests the subject will be seated in an upright position and the dynamometer will be placed proximal to the wrist at the level of the ulnar styloid process for external rotation and internal rotation, and distal humerus for forward elevation. For each measurement, a “make test” will be used which consists of the examiner holding the dynamometer in the desired testing position and then the subject is asked to exert maximal force against the dynamometer for 5 seconds.[63,64] Each measurement will be performed three times. The average of the three trials will be used for subsequent analysis.

Shoulder Range of Motion (ROM): Bilateral active and passive shoulder ROM (forward elevation, abduction, external rotation at 0 degrees abduction, external rotation at 90 degrees abduction) will be assessed with a goniometer using standardized patient positioning.[65] Bilateral active and passive shoulder internal rotation ROM will be measured by the vertebral level reached by the thumb as the hand is placed behind the back and up the spine as far as possible.[63] Each measurement will be performed once.

Pectoralis Minor Resting and Elongated Length: A PALpation Meter (PALM) caliber will be used to measure bilateral pectoralis minor resting and elongated length. Pectoralis minor resting and elongated length will be defined as the distance from the coracoid process to the inferior aspect of the 4th rib just lateral to (1 finger width) the sternal-costal junction. For resting length, subjects will stand in their normal relaxed posture while the measurement is taken. For elongated length, subjects will fully elevate and retract their scapula and hold this position while the measurement is taken. Each measurement will be performed twice. The average of the two trials will be used for subsequent analysis.

Resting Scapular Alignment: For visual assessments subjects will be asked to wear a halter-top. Subjects will stand in their natural, relaxed posture while the examiner assesses the resting alignment of each scapula on the thorax from posterior, lateral, anterior views. From this procedure the examiner evaluates whether or not: 1) the scapula lies flat against the upper back, 2) the vertebral border of the scapula is parallel to the thoracic spinous processes 3) the clavicle is either horizontal or elevated by 6-10 degrees at the acromial end, and 4) the acromion is forward respect to the center of the thorax (Table 5).

Table 5: Operational definitions for resting scapular alignment

Normal	Mal-alignment
Scapula lies flat against upper back.	Scapula is winging, with either the medial border and/or inferior angle displaced off the thorax.
Vertebral borders are parallel to spinous processes.	Medial-lateral difference exists between root of the scapular spine and inferior angle of the scapula with respect to the thoracic spine midline (upward or downward rotation).
From a frontal view, the clavicle is either horizontal or elevated by 6-10 degrees at the acromial end.	From a frontal view, the clavicle is either depressed *or* elevated by more than 10 degrees at the acromial end.
From a lateral view, the midpoint of the acromion is centered with respect to the midline of the thorax.	From a lateral view, the midpoint of the acromion is anterior or posterior to the midline of thorax.
Subtle = mild or questionable mal-alignment **Obvious =** marked or clearly apparent mal-alignment **Final Rating:** ***Normal:*** All normal ratings or 1 subtle rating ***Subtle abnormality:*** 2 or more subtle ratings ***Obvious abnormality**:* At least 1 obvious rating	

Visual Assessment of Scapular Motion: Subjects will perform a modified version of the scapular dyskinesis test.[66] The scapular dyskinesis test consists of 5 repetitions of bilateral, active shoulder flexion and shoulder abduction. Subjects will be asked to raise (3-second count) and lower (3-second count) their arms while keeping their elbows straight and thumbs pointed up. Each motion will be demonstrated, and subjects will be asked to perform a few practice trials. The Visual Scapular Dyskinesis Test will be conducted during kinematic data collection. Operational definitions and rating scale for the scapular dyskinesis test were taken from McClure et al[66] (Table 6).

Table 6: Operational definitions scapular dyskinesis test [66]

<table>
<tr><td>Normal shoulder complex rhythm</td><td>The scapula is stable with minimal motion during the initial 30° to 60° of humerothoracic elevation, then smoothly and continuously rotates upward during elevation and smoothly and continuously rotates downward during humeral lowering. No evidence of winging is present.</td></tr>
<tr><td>Scapular dyskinesis</td><td>Either or both of the following motion abnormalities may be present.</td></tr>
<tr><td></td><td>Dysrhythmia: The scapula demonstrates premature or excessive elevation or protraction, non-smooth or stuttering motion during arm elevation or lowering, or rapid downward rotation during arm lowering.</td></tr>
<tr><td></td><td>Winging: The medial border and/or inferior angle of the scapula are posteriorly displaced away from the posterior thorax.</td></tr>
<tr><td colspan="2"><u>Rating Scale</u>

Each test movement (flexion and abduction) rated as:
a) Normal motion: no evidence of abnormality

b) Subtle abnormality: mild or questionable evidence of abnormality, not consistently present

c) Obvious abnormality: striking, clearly apparent abnormality, evident on at least 3/5 trials (dysrhythmias or winging of 1 in (2.54 cm) or greater displacement of scapula from thorax)

Final rating is based on combined flexion and abduction test movements.

Normal: Both test motions are rated as normal or 1 motion is rated as normal and the other as having subtle abnormality.

Subtle abnormality: Both flexion and abduction are rated as having subtle abnormalities.

Obvious abnormality: Either flexion or abduction is rated as having obvious abnormality.</td></tr>
</table>

Shoulder Special Tests: The following special tests for rotator cuff disease will be performed on each of the subjects' shoulders: Neer impingement sign, Hawkins-Kennedy test, empty can test, resistive external rotation test, painful arc sign, and external rotation lag signs. Special tests will be recorded as "positive" or "negative" as described in Table 7.

Table 7: Operational Definitions for Special Tests[67-69]

Neer impingement sign:	Examiner stabilizes the scapula with a downward force while passively flexing the humerus overhead maximally with overpressure. A positive test is reproduction of pain at the superior or superolateral aspect of the shoulder.
Hawkins-Kennedy:	With the arm and elbow flexed to 90 degrees, examiner passively internally rotates humerus maximally with overpressure. A positive test is reproduction of pain at the superior or superolateral aspect of the shoulder.
Empty can test:	With the arm elevated 90 degrees in the plane of the scapular and internally rotated (thumb pointing towards ground), the examiner applies a downward directed force at the wrist while the subject attempts to resist. A positive test is weakness or reproduction of pain at the superior or superolateral aspect of the shoulder.
External rotation resistance test:	With the arm at the subject's side and elbow flexed 90 degrees, examiner applies an internal rotation force at the wrist while the subject attempts to resist. A positive test is weakness or reproduction of pain at the superior or superolateral aspect of the shoulder.
External rotation lag signs:	Examiner supports the arm elevated 20 degrees in the plane of the scapula with the elbow flexed 90 degrees. Examiner maximally externally rotates arm. The subject is asked to maintain the arm in maximal external rotation. A positive test is an inability to maintain external rotation or a lag of more than 5 degrees into internal rotation. The test is repeated with the arm supported in 90 degrees of elevation in the scapular plane.
Painful arc sign:	The subject is asked to actively abduct his/her arm and report any pain during the motion. A positive test is superior or superolateral shoulder pain reported by the subject between 60 and 120 degrees of abduction.

Lymphedema Assessment

Lymphedema Assessment of Breast Arm and Torso (LABAT): Each subject will undergo an assessment for lymphedema based on the Common Toxicity Criteria version 3.0[70] (Table 8). This involves assessing tissue texture, obscuration of anatomical architecture, deviation from normal anatomical contour, obliteration of skin folds, presence of pitting or non-pitting edema, Stemmer's sign, limb volume, and alterations of activities of daily living because of symptoms.

Table 8: Common Toxicity Criteria version 3.0[70]

Stage	Definition[70]
Stage 1	5%-10% inter-limb discrepancy in volume or circumference at point of greatest visible difference; swelling or obscuration of anatomic architecture on close inspection pitting edema
Stage 2	10-30% inter-limb discrepancy in volume or circumference at point of greatest visible difference; readily apparent obscuration of anatomic architecture; obliteration of skin folds; readily apparent deviation from normal anatomic contour
Stage 3	30% inter-limb discrepancy in volume; lymphorrhea; gross deviation from normal anatomic contour; interfering with ADL
Stage 4	Progression to malignancy (i.e., lymphangiosarcoma); amputation indicated; disabling

Upper extremity limb volume: A tape measure will be used to obtain circumferential measurements at the MCP joints, palm, wrist (ulnar styloid), and 4 cm intervals from the wrist to shoulder. Total limb volume will be obtained by adding the volumes of the truncated cones between these points.[71] For woman with a history of breast cancer treatment, the percent difference between limbs will be calculated by the following formula: (limb volume affected-limb volume unaffected)/limb volume unaffected. For women without a history of breast cancer treatment, the percent difference will be calculated by (limb volume dominant side-limb volume non-dominant side)/limb volume non-dominant. Each circumferential measurement will be performed once. Each woman's lymphedema status will be graded based on the criteria found in Table 9.

Table 9: Operational Definitions for Lymphedema Grade

Grade	Definition
0	<5% inter-limb discrepancy in volume; no obscuration of anatomical architecture; normal anatomical contour; no pitting or non-pitting edema; normal tissue texture; negative Stemmer's Sign; no obliteration of skin folds
1	<10% inter-limb discrepancy in volume; and obscuration of anatomical architecture on close inspection; normal anatomical contour; pitting or non-pitting edema with spongy or firm tissue texture
2	11-20% inter-limb discrepancy in volume; or readily apparent obscuration of anatomical architecture; normal anatomical contour; pitting or non-pitting edema with spongy or firm tissue texture
3	21-30% inter-limb discrepancy in volume; or readily apparent obscuration of anatomical architecture; readily apparent deviation from normal anatomical contour; pitting or non-pitting edema with spongy or firm tissue texture
4	>31% inter-limb discrepancy in volume; or or readily apparent obscuration of anatomical contour; gross deviation of normal anatomical architecture; pitting or non-pitting edema with spongy or firm tissue texture

A review of the literature was conducted to determine the reliability and/or measurement error of the clinical measures. The results of this review can be found in Table 10.

Table 10: Summary of literature investigating the reliability and measurement error associated with clinical shoulder measures.

Authors	Subjects	Clinical Measure	ICC	SEM	MDC (90%)
Mintken et al. 2009[58]	101 adults with shoulder pain who received physical therapy (mean age +/- SD of stable patients = 44.4 +/- 17.4 years; mean age +/- SD of improved patients = 39.1 +/- 18.8 years)	Numeric Pain Rating Scale	Test-retest = .74	1.07 points	2.5 points
Leggin et al. 1996[64]	17 adults (7 men with mean age = 31 +/- 5 years; 10 women with mean age 30 +/- 6 years) with no known shoulder dysfunction	Shoulder Strength	Intra-rater IR=.94- .97 ER=.89- .95 Ele=.84-.96 Inter-rater IR=.90 ER=.94 Ele=.79	Not reported	Not reported
Leggin et al. 2003[72]	40 adults (22 men with mean age = 42.4 +/- 11.7 years; 18 women with mean age = 54.8 +/- 17.1 years) receiving post-operative or non-operative rehabilitation for a variety of shoulder conditions	Shoulder Strength	Interrater IR=.91 ER=.89 Ele=.93	IR=2.2kg ER=1.4kg Ele=1.9kg	IR=3.1kg ER=3.3kg Ele=2.7kg

ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC = minimal detectable change; ROM = range of motion; ABD = abduction; FE = forward elevation; ER = external rotation; IR = internal rotation; Ele = elevation; V = volume; h = height; C = circumference

Table 10 (continued): Summary of literature investigating the reliability and measurement error associated with clinical shoulder measures.

Authors	Subjects	Clinical Measure	ICC	SEM	MDC (90%)
Leggin et al. 2003[72]	40 adults (22 men with mean age +/- SD = 42.4 +/- 11.7 years; 18 women with mean age +/- SD = 54.8 +/- 17.1 years) receiving post-operative or non-operative rehabilitation for a variety of shoulder conditions	Shoulder ROM	Interrater FE=.89 ER at 0°=.89 ER at 90°=.88 IR=.86	FE=12.3° ER at 0°=10.3° ER at 90°=17.9° IR=2 levels	FE=17.4° ER at 0°=14.6° ER at 90°=25.3° IR=3 levels
Leggin et al. 2003[72]	40 adults (22 men with mean age +/- SD = 42.4 +/- 11.7 years; 18 women with mean age +/- SD = 54.8 +/- 17.1 years) receiving post-operative or non-operative rehabilitation for a variety of shoulder conditions	Shoulder ROM	Interrater FE=.89 ER at 0°=.89 ER at 90°=.88 IR=.86	FE=12.3° ER at 0°=10.3° ER at 90°=17.9° IR=2 levels	FE=17.4° ER at 0°=14.6° ER at 90°=25.3° IR=3 levels
Harrington et al. 2011	Pilot data on breast cancer survivors (number of subjects was not reported)	Shoulder AROM/ PROM	Intrarater AROM = .84-1.0 PROM = .97-1.0	Not reported	Not reported

ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC = minimal detectable change; ROM = range of motion; ABD = abduction; FE = forward elevation; ER = external rotation; IR = internal rotation; V = volume; h = height; C = circumference

Table 10 (continued): Summary of literature investigating the reliability and measurement error associated with clinical shoulder measures.

Authors	Subjects	Clinical Measure	ICC	SEM	MDC (90%)
Ebaugh and Oravitz, 2008[73]	8 healthy subjects (4 men; mean age = 24.1 years)	Pectoralis Minor Length (resting and elongated)	Intra-rater = .98-.99 Inter-rater = .86-.95	Not reported	Intra-rater .5 – .8 cm Inter-rater 1.4 – 2.2 cm
Sander et al. 2002[74]	50 women with primary or secondary lymphedema (mean age +/- SD = 56 +/- 13.3 years)	Limb volume $V = \Sigma (hC_i^2/4\pi)$ h = 3, 6, or 9cm	Intra-rater = .99 Inter-rater = .99	h= 3cm: 120mL h= 6cm: 124 mL h= 9cm: 130mL	Not reported
Deltombe et al. 2007[75]	30 women with unilateral breast cancer related lymphedema (mean age +/- SD = 63 +/- 9 years)	Limb volume $V = \Sigma (hC_i^2/4\pi)$ h = 5cm	Intra-rater = .99 Inter-rater = .99	Not reported	Not reported
Czerniec et al. 2010[76]	33 women with breast cancer related lymphedema (mean age +/- SD = 58.6 +/- 10 years); 18 women without history of either lymphedema or breast cancer (mean age +/- SD = 52.2 +/-7 years)	Limb volume $V=\Sigma\, h\,(C_i^2+C_i^2C_{i-1}^2+C_{i-1}^2)\,/12\pi$ h = 10 cm	Lymphedema group Inter-rater = .98 Control group Inter-rater = .98	93mL	Not reported

ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC = minimal detectable change; ROM = range of motion; ABD = abduction; FE = forward elevation; ER = external rotation; IR = internal rotation; V = volume; h = height; C = circumference

Review of the literature revealed no data supporting the intra or inter-rater reliability of visual assessment of resting scapular alignment. Our lab developed the procedures and operational definitions for the resting scapular alignment measure based on a review of the literature. A pilot study was conducted to determine the intra-rater and inter-rater reliability of visual assessment of resting scapular alignment and visual assessment of scapular motion. The results of this study revealed that when individuals were rated as normal or abnormal visual assessment of resting scapular alignment had moderate to substantial agreement within and between raters and visual assessment of scapular motion had fair to almost perfect agreement within and between raters.[77,78] Kappa values (95% CI) for intra-rater reliability of resting scapular alignment across 3 raters ranged from .41 to .64 (.02-1.0). Kappa value (95% CI) for inter-rater reliability (average kappa values between raters) was .67 (.30-0.98). Kappa values (95% CI) for intra-rater reliability of scapular motion across 3 raters ranged from .36 to .93 (.12-1.0). Kappa value (95% CI) for inter-rater reliability (average kappa values between raters) was .41 (.11-0.86).

Instrumentation

Instrumented measures of scapular, clavicular, and humeral motion will be collected using an electromagnetic position tracking system (Liberty™, Polhemus, Colchester, Vermont).

Continuous kinematic data will be collected on the shoulder complex at a sampling frequency of 120Hz per sensor. The validity of electromagnetic tracking systems for measuring scapulothoracic motion has been established.[55,79] In the proposed study 5 sensors will be placed on the subjects in the following locations: 1) sternum just inferior to the sternal notch, 2) left scapula via means of a custom made scapular jig[79], 3) right scapula via means of a custom made scapular jig[79], 4) left humerus by means of a humeral cuff[80], and 5) right humerus by means of a humeral cuff.[80] Adhesive tape, wig glue (spirit gum adhesive), and Velcro strips will be used to secure the sternal receiver and scapular jigs to the skin and elastic straps will secure the humeral cuff on the distal arm.[81] While standing in a natural relaxed posture, bony landmarks on the thorax, scapula, and humerus will be digitized to create local body reference frames.[82]

d. Procedures

Interested women will be contacted, and provided a brief description of the study. A telephone screening will be performed in order to determine her eligibility (*Appendix B*). Potential subjects will be scheduled for an appointment at the research laboratory where they will again be provided with a brief description of the study. Those subjects who are willing to participate will read and sign the informed consent form.

Descriptive data will be collected including age, hand dominance, side affected, time since surgery, type of surgery (mastectomy/lumpectomy, SLNB/ALND), chemotherapy (yes/no), chemotherapy drugs, radiation (yes/no), radiation field (breast, chest wall, regional lymph nodes), history of physical therapy, home exercise program, and current exercise routine (*Appendix C*). Subjects will complete questionnaires addressing self-report of pain and disability, fear of physical activity/exercise, and health related quality of life.

A clinical examination will be conducted including active and passive shoulder

ROM, shoulder strength, pectoralis minor length, and resting scapular alignment (*Appendix D)*. A lymphedema assessment according to the Common Toxicity Criteria will be performed (*Appendix E)*. A tape measure will be used to collect the following anthropometric measurements: sternum length clavicle length, shoulder height, and arm length (*Appendix F)*. Shoulder height will be measured from the anterior aspect of the acromion process to the ground [21]. The length of each subject's arm will be measured from the anterior aspect of the acromion process to the tip of the middle finger while the subject is seated, with the elbow extended at the their side.[21] Sternum length and clavicle length will be used for pectoralis length normalization. Shoulder height and arm length will be used to standardize shelf height for the reaching task.

Following this, kinematic sensors will be attached to the subject as previously described. While standing in a natural relaxed posture, bony landmarks on the thorax, scapula, and humerus will be digitized to create local body reference frames.[82] Kinematic data will be collected while the subject performs five repetitions of the following tasks: 1) un-weighted shoulder flexion, 2) weighted shoulder flexion, 3) un-weighted shoulder abduction, 4) weighted shoulder abduction, 5) un-weighted scapular plane arm elevation, 6) weighted scapular plane arm elevation, 7) un-weighted overhead reaching, 8) weighted overhead reaching, and 9) simulated washing/combing hair. For all trials subjects will be instructed to stand in their natural upright position and not move their feet as they raise and lower their arms. Each trial of arm raising and lowering will be performed within 2-4 seconds and subjects will be allowed to practice until they are comfortable performing the motion. A two-minute rest period will be provided between tasks to reduce the risk of fatigue. The order in which the tasks will be performed will be randomized.

For the first 6 tasks subjects will move both arms simultaneously. For the overhead reaching tasks subjects will move one arm at a time. The overhead reaching tasks require subjects to transfer a small object from in front of them to an overhead shelf and back. Shelf height will be normalized using anthropometric data from each subject. The bottom shelf will be positioned at a horizontal distance of 60% arm length and height of 50% of arm length below shoulder height. The top shelf will be positioned at a horizontal distance of 60% arm length, and a height of 50% of arm length above shoulder height. For weighted tasks, subjects will lift 0.91 kg (2 lbs.), which is similar to lifting a large can of soup (1.2 lbs.) and less than a half gallon of milk (4.3 lbs.). For simulated washing/combing hair, subjects will reach to the top of their head.

e. Kinematic Data Reduction

Digitized boney landmarks, establishment of local coordinate systems, and description of scapular, clavicular, and humeral motions will generally follow the recommendations of The International Society of Biomechanics.[82] Descriptions of scapular motion relative to the thorax (scapulothoracic), humeral motion relative to the scapula (glenohumeral), and humeral motion relative to the thoracic (humerothoracic) can be found in *Appendix A*.

For <u>specific aim 1, working hypothesis “a” and “b”,</u> a LabView linear interpolation program will be used to determine the amount of scapulothoracic and glenohumeral motion during the raising phase of each of the previously mentioned tasks. The mean from trials 2 - 4 will be calculated.

For specific aim 1, working hypothesis "c", a LabView program will be used to filter [zero lag, 4th order Butterworth filter (8Hz)] and resample (101 points) kinematic data across a common range of humerothoracic elevation that will be performed during trials 2 – 4 of the overhead reaching tasks.

In order to provide insight into shoulder complex coordination, angle-angle graphs and relative motion graphs will be created. Angle-angle graphs will be created for all scapular and clavicular rotations by plotting scapular or clavicular motion on the X-axis and humeral motion on the Y-axis (Figure 3). Data obtained from angle-angle graphs will be used to calculate each coupling angle, which is defined as the angle between the vector formed between two adjacent data points relative to the right horizontal. [83,84] Relative motion graphs plot percent of movement on the X-axis and coupling angles on the Y-axis (Figure 4).

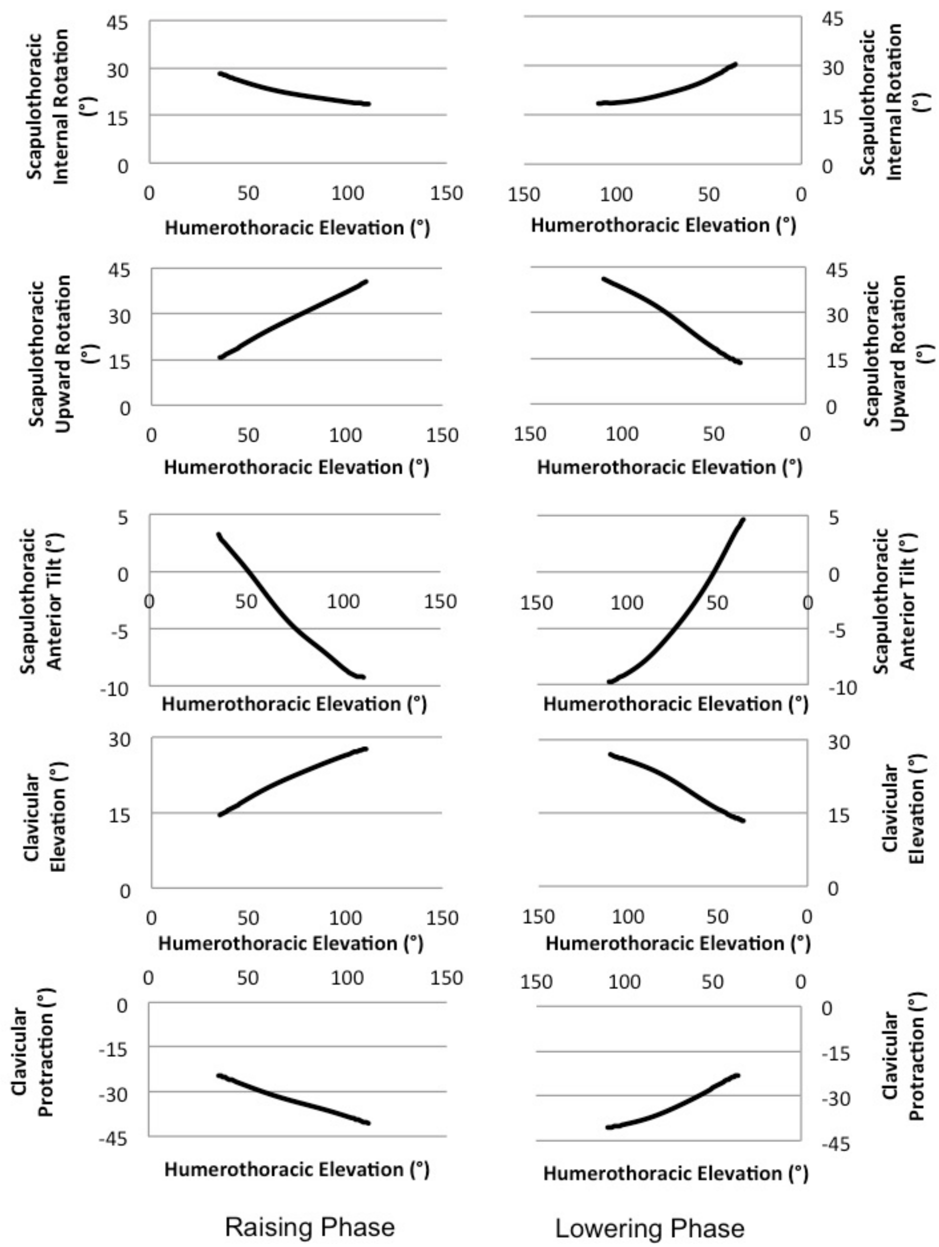

Figure 3: Angle-Angle Plots: Scapular and clavicular angular position on "Y" axis and humerothoracic elevation angular position on "X" axis

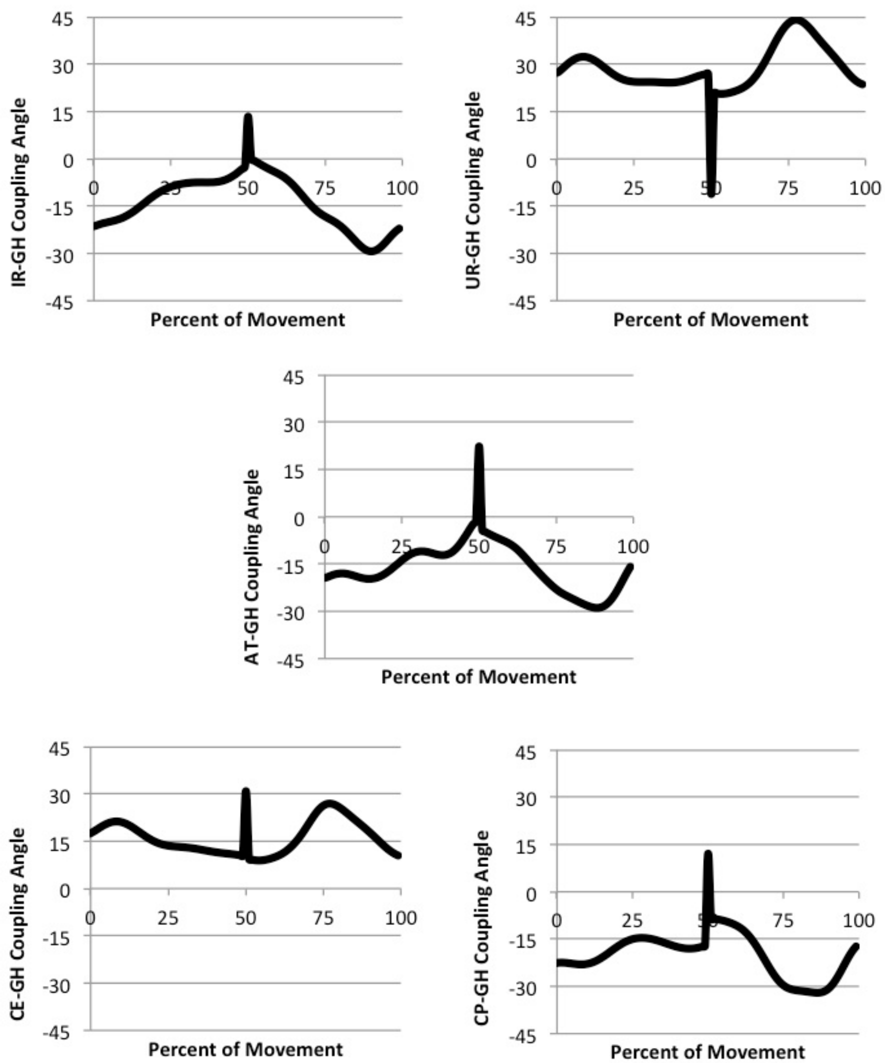

Figure 4: Relative motion plots: scapular and clavicular coupling angle on "Y" axis and percent of movement on "X" axis

IR – internal rotation; UR –upward rotation; AT – anterior tilt; CE – clavicular elevation; CP – clavicular protraction; GH - glenohumeral

f. Data Analysis

Specific Aim 1: Determine the effect that breast cancer treatments (surgery and radiation) have on shoulder complex motion and coordination.

Working hypothesis 1a: Women with a history of surgery and radiation will demonstrate greater impairments in shoulder complex motion during functional reaching tasks when compared to women with surgery only.

Working hypothesis 1b: Women with a history of surgery only will demonstrate impairments in shoulder complex motion during functional reaching tasks compared to women without a history of breast cancer treatment.

The primary variables of interest are scapular, clavicular, and humeral range of motion (scapular internal/external rotation, upward/downward rotation, anterior/posterior tilt; clavicular protraction/retraction, elevation/depression; glenohumeral adduction/abduction, elevation/depression, internal/external rotation, and humerothoracic elevation/depression) during overhead reaching and simulated combing hair. Range of motion will be defined as maximum angle minus resting angle. A one-way multivariate analysis of variance (MANOVA) will be conducted to determine whether differences in scapular, clavicular, and humeral range of motion exist between groups (surgery and radiation, surgery only, and no breast cancer). The involved side in women with breast cancer will be matched by hand dominance with the appropriate side in women without breast cancer.

Working hypothesis1c: A greater percentage of women with a history of surgery and radiation will demonstrate impaired shoulder complex coordination during functional reaching tasks compared to women with a history of surgery only.

The primary variable of interest is the frequency of women treated with surgery and radiation, and surgery only who demonstrate impaired patterns of shoulder complex coordination. Angle-angle and relative motion graphs, for each subject with a history of breast cancer, will be plotted against comparative profiles derived from women in the control group. These comparative profiles will consist of averaged graphs with 95% MDCB for all scapular and clavicular angle-angle and relative motion graphs. All graphs will be divided into 4 phases of the total movement: 0%-24%, 25%-50%, 51%-75%, and 76%-100%. Individuals will be considered to have impaired shoulder complex coordination when a rotation lies outside the MDCB for at least 2 of the 4 phases, or at least 2 rotations fall outside the MDCB for at least 1 phase. The percentage of women treated with surgery and radiation, and surgery only who present with impaired patterns of shoulder complex coordination will be calculated. Fisher Exact Test will be used to determine whether there is a difference in the proportion of women who demonstrate impaired coordination in women treated with surgery and radiation, and surgery only. For this analysis the involved side of the women with breast cancer will be matched by hand dominance with the appropriate side of women without breast cancer.

Specific Aim 2: Identify clinical factors associated with impaired shoulder complex coordination in women with a history of breast cancer treatment.

Working hypothesis 2: Pain, decreased shoulder complex muscle strength, decreased pectoralis muscle flexibility, altered resting scapular alignment, and upper extremity lymphedema will be associated with impaired shoulder complex coordination.

Individual variables from the musculoskeletal and lymphedema assessments will be tested to determine whether there is a significant difference between women with and without impaired coordination by using independent t-tests for continuous variable and Mann-Whitney U test for ordinal variables.[85]

A receiver operator characteristic (ROC) curve analysis will be performed on any continuous and ordinal variable found to be significant.[85] The ROC curve will be used to determine a cut off score associated with impaired coordination.[85] Sensitivity, specificity, positive and negative likelihood ratios with 95% confidence intervals will be calculated based on the cutoff score.[85]

Only variables significantly different between women with and without impaired coordination ($p < 0.10$) will be included as potential predictors in the regression model. A logistic regression will be used to determine the associations of clinical factors with impaired shoulder complex coordination.

g. Potential Problems and Alternate Strategies

Some individuals may not be able to perform the overhead reaching task at the predetermined shelf height secondary to motion restrictions. In this situation the shelf will be placed at a height that the individual can reach and this new shelf height will be recorded.

The activities that the women will participate in are consistent with activities of daily living and a standard physical therapy examination of the shoulder complex. However, if an individual experiences fatigue or shoulder pain while performing any of the required activities they will be provided with increased rest times. Although the adhesive material used to attach the sensors to the skin is hypoallergenic and designed for skin use, it is possible that minor skin irritation could occur. In the rare case where skin irritation occurs the subject will be told to contact their physician if it does not clear within 24 hours.

If difficulty in recruiting occurs, the Cancer Support Community: Philadelphia and other community-based organizations will be contacted to request an opportunity to present the research proposal and post flyers. An offer will be made to provide education to women with a history of breast cancer. Topics may include benefits of exercise or lymphedema risk reduction.

1G: TIMELINE

	Recruit	Collect Data	Data Reduction	Data Analysis	Write Aim 1	Write Aim 2	Defend
Nov 2012							
Dec 2012							
Jan 2013							
Feb 2013							
March 2013							
April 2013							
May 2013							
June 2013							
July 2013							
Aug 2013							
Sept 2013							
Oct 2013							X

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1I: RESOURCES NEEDED TO COMPLETE DISSERTATION

Laboratory: The Neuromuscular Performance Lab is a 412 sq. ft. space located in the Rehabilitation Sciences Research Laboratories at Drexel University.

Equipment: Polhemus Liberty System is an electromagnetic device needed to collect 3-dimensional kinematic data. PALM (Palpation Meter) is a caliber needed to collect pectoralis minor length data. Lafayette Manual Muscle Test System is a dynamometer needed to collect shoulder strength data.

Computer: PC with Labview 8.6 located in the Drexel University biomechanics laboratory is needed for data collection, processing, and reduction.

Supplies: Velcro, double-sided tape, skin pen, alcohol pads, and halter-tops are need for kinematic set-up. A tape measure is needed to measure limb circumferences. A goniometer is needed to measure shoulder range of motion.

1J: APPENDICES

Appendix A:

Description of Scapular, Clavicular and Humeral Motions

Scapular and Clavicular Motions

The position and orientation of the scapula relative to thorax (scapulothoracic) will be described as 3 scapular and 2 clavicular rotations. Scapular rotations will be described using an Euler angle sequence (z, y', x''), where scapular internal/external rotation occurs about the vertically oriented z-axis, upward/downward rotation occurs about the anteriorly oriented y-axis, and anterior/posterior tilt occurs about the laterally oriented x-axis. Motions of the clavicle with respect to the thorax will not measured directly, but will be derived from boney landmarks on the sternum and scapula. These motions consist of clavicular elevation/depression (representing scapular superior/inferior translation) and clavicular protraction/retraction (representing scapular anterior/posterior translation).

Humeral Motions

Motions of the humerus relative to the scapula (glenohumeral) will be described as glenohumeral elevation, adduction/abduction, and internal/external rotation using y, x', z'' Cardan angles. An Euler angle sequence of z, y', z'' will be used to describe motions of the humerus relative to the thoracic (humerothoracic), which will be defined as humerothoracic adduction/abduction, elevation/depression, and internal/external rotation.

Appendix B

Eligibility Screening Examination

	Yes	No
Have you ever been treated for breast cancer? **(If no, skip to questions A-F for eligibility of women without BrCa)**		
Have you had surgery to remove any lymph nodes (ie sentinel lymph node biopsy or axillary lymph node dissection)?		
Did you have your entire breast removed (mastectomy), undergo a breast reconstruction, and NOT receive radiation **Or** **Did you have a portion of your breast removed (lumpectomy) and receive radiation to your breast?**		
Was your surgery more than 1 year ago but less than 3 years ago?		
Are you between the ages of 30 and 70 years?		
Can you raise your arms overhead?		
Did you receive chemotherapy or radiation? (if no, skip to question 10)		
Have you finished your chemotherapy or radiation treatments?		
Did you finish your chemotherapy or radiation treatments more than 6 months ago?		
Do you have a history of shoulder pain prior to your breast cancer diagnosis that required medical intervention?		
Do you have a history of any conditions affecting your neck or arms? (ie stroke, fracture, dislocation, nerve injury)		
Do you have an allergy to adhesive materials?		

Subjects with a history of breast cancer who qualify:
“Yes” to questions 1-6, 8, 9
“No” to questions 10-12

	Yes	No
Have you ever been treated for breast cancer?		
Do you have a history of shoulder pain that required medical treatment?		
Do you have a history of any conditions affecting your neck or arms? (ie stroke, fracture, dislocation, nerve injury)		
Do you have an allergy to adhesive materials?		
Are you between the ages of 30 and 70 years?		
Can you raise your arms overhead?		

Subjects without a history of breast cancer who qualify
“Yes” to questions E and F
“No” to questions A-D

Appendix C

Descriptive Data Form

Age (years)	
Hand Dominance	Left Right Ambidextrous
History of breast cancer treatment	No Yes
If answer to history of breast cancer treatment is “yes” obtain information below	
Side Affected	Left Right
Type of Surgery	Lumpectomy Mastectomy
Date of Surgery	
Reconstruction	No Yes (Type:_______________)
Type of lymph node surgery	SLND AND
Number of lymph nodes removed	
Date of lymph node surgery	
Radiation	No Yes
Location of radiation	Partial Breast Full breast Axilla SCF
Type of radiation	External Beam Brachytherapy Other: ___________
Dates of radiation	

Chemotherapy	No Yes (Type: ___________________)
Dates of chemotherapy	
Hormone therapy	No Yes (Type: ___________________)
Currently on hormone therapy	No Yes (Type: ___________________)
Level of pain at rest (0-10/10)	
Location	
Level of pain during arm motion (0-10/10)	
Location	
History of physical therapy	Yes No
Number of visits	

HEP prescribed	Yes No
HEP description (type and frequency prescribed)	
What percentage of time did you perform your HEP?	0% 25% 50% 75% 100%
Still perform HEP	Yes No
Frequency of HEP	
Currently Exercise	Yes No
Type of exercise	
Frequency of exercise	

Appendix D

Clinical Examination Forms and Procedures

Shoulder Range of Motion, Shoulder Strength, Pectoralis Minor Length Data Collection Form

Shoulder Range of Motion (Degrees)				
	AROM		**PROM**	
	Right	**Left**	**Right**	**Left**
FE				
Abduction				
ER at 0				
ER at 90				
IR (hand up back)				

Muscle Strength (kg force)						
	Right			**Left**		
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**
Elevation						
ER						
IR						

Pectoralis Minor Length (cm)				
	Right		**Left**	
	Trial 1	**Trial 2**	**Trial 1**	**Trial 2**
Resting				
Elongated				

Clinical Assessment of Resting Scapular Alignment: Rating Form

	Left		Right	
	Normal	Abnormal	Normal	Abnormal
Scapula lies flat against upper back		S O		S O
Vertebral borders parallel to SPs		S O		S O
Root of scapular spine at T3-T4		S O		S O
Clavicle is either horizontal or elevated by 6-10 degrees at the acromial end.		S O		S O
Scapula is forward respect to the thorax		S O		S O
Final Score				

S = subtle, questionable presence of mal-alignment
O = obvious, marked presence of mal-alignment

Remarks:

Scapula lies flat against upper back:	
Vertebral borders parallel to SPs:	
Root of scapular spine at T3-T4 level:	
Clavicle is either horizontal or elevated by 6-10 degrees at the acromial end:	
Scapula is forward respect to thorax:	

Shoulder Special Tests Data Collection Form

	Right	**Left**
Neers	Positive ☐ Negative ☐	Positive ☐ Negative ☐
Hawkins	Positive ☐ Negative ☐	Positive ☐ Negative ☐
Empty Can	Pain: Positive ☐ Negative ☐ Weak: Positive ☐ Negative ☐	Pain: Positive ☐ Negative ☐ Weak: Positive ☐ Negative ☐
Resistive ER	Pain: Positive ☐ Negative ☐ Weak: Positive ☐ Negative ☐	Pain: Positive ☐ Negative ☐ Weak: Positive ☐ Negative ☐
ER lag at 20 degrees	Positive ☐ Negative ☐	Positive ☐ Negative ☐
ER lag at 90 degrees	Positive ☐ Negative ☐	Positive ☐ Negative ☐
Painful arc	Positive ☐ Negative ☐	Positive ☐ Negative ☐

Clinical Assessment of Scapular Dyskinesis: Rating Form

	Left			Right		
	Normal	Subtle	Obvious	Normal	Subtle	Obvious
Unweighted Flexion		W D	W D		W D	W D
Unweighted Abduction		W D	W D		W D	W D
Weighted Flexion		W D	W D		W D	W D
Weighted Abduction		W D	W D		W D	W D
Final Score						

W= winging
D= dyskinesis

Remarks:

Un-weighted flexion:	
Un-weighted abduction:	
Weighted flexion:	
Weighted abduction:	

Appendix E:

Lymphedema Assessments

Circumferential Measurements Data Collection Form

	Right	Left
MCPs		
Palm		
Wrist		
4 cm		
8 cm		
12 cm		
16 cm		
20 cm		
24 cm		
28 cm		
32 cm		
36 cm		
40 cm		
44 cm		
48 cm		
52 cm		
Comments:		

Lymphedema Assessment Breast Arm and Torso (LABAT)

Upper Extremity Assessment

Stemmer's Sign

	Right			Left		
	No	Yes	Digit (1-5)	No	Yes	Digit (1-5)
Digits	O	O	________	O	O	________

Obliteration of skin folds

	Right			Left		
	No	Yes	Digit (1-5)	No	Yes	Digit (1-5)
Digits	O	O	________	O	O	________

Obscuration of Anatomical Architecture

	Right			Left		
	No	Close inspection	Readily apparent	No	Close inspection	Readily apparent
Knuckles	O	O	O	O	O	O
Extensor tendons	O	O	O	O	O	O
Ulnar Styloid	O	O	O	O	O	O
Flexor tendons	O	O	O	O	O	O
Infracondylar recess	O	O	O	O	O	O
Olecranon Process	O	O	O	O	O	O
Veins	O	O	O	O	O	O
Location	________________		ONA	________________		ONA

Anatomical Contour Change

	Right			Left		
	No	Readily apparent	Gross deviation	No	Readily apparent	Gross deviation
Dorsal hand	O	O	O	O	O	O
Wrist	O	O	O	O	O	O
Forearm	O	O	O	O	O	O
Elbow	O	O	O	O	O	O
Upper arm	O	O	O	O	O	O

Edema

	Right			Left		
	None	Non-Pitting	Pitting	None	Non-pitting	Pitting
Fingers	O	O	O	O	O	O
Dorsum	O	O	O	O	O	O
Wrist	O	O	O	O	O	O
Forearm	O	O	O	O	O	O
Elbow	O	O	O	O	O	O
Upper Arm	O	O	O	O	O	O

Tissue Texture

	Right				Left			
	Normal	Spongy	Firm	Hard	Normal	Spongy	Firm	Hard
Fingers	O	O	O	O	O	O	O	O
Dorsum	O	O	O	O	O	O	O	O
Wrist	O	O	O	O	O	O	O	O
Forearm	O	O	O	O	O	O	O	O
Elbow	O	O	O	O	O	O	O	O
Upper Arm	O	O	O	O	O	O	O	O

Breast/Torso Assessment

Edema

	Right			Left		
	None	Non-Pitting	Pitting	None	Non-pitting	Pitting
Breast/Anterior trunk						
UOQ	O	O	O	O	O	O
UIQ	O	O	O	O	O	O
LOQ	O	O	O	O	O	O
LIQ	O	O	O	O	O	O
Lateral trunk	O	O	O	O	O	O
Posterior trunk	O	O	O	O	O	O

Tissue Texture

	Right				Left			
	Normal	Spongy	Firm	Hard	Normal	Spongy	Firm	Hard
Breast/Anterior Trunk								
UOQ	O	O	O	O	O	O	O	O
UIQ	O	O	O	O	O	O	O	O
LOQ	O	O	O	O	O	O	O	O
LIQ	O	O	O	O	O	O	O	O
Lateral trunk	O	O	O	O	O	O	O	O
Posterior trunk	O	O	O	O	O	O	O	O

Peau d'orange

	Right		Left	
	No	Yes	No	Yes
Breast/Anterior Trunk				
UOQ	O	O	O	O
UIQ	O	O	O	O
LOQ	O	O	O	O
LIQ	O	O	O	O
Lateral trunk	O	O	O	O
Posterior trunk	O	O	O	O

Comments:

Interfere with Activities of Daily Living?

Are you UNABLE to perform any activities of daily living such as dressing or washing self because of your lymphedema?

O No O Yes O Not applicable

Appendix F

Anthropometric Data Collection Form

	Right	Left
Sternum Length		
Clavicle Length		
Shoulder Height		
Arm Length		
50 % Arm Length		
Bottom Shelf Height (Shoulder Height minus 50% Arm Length)		
Top Shelf Height (Shoulder Height plus 50% Arm Length)		
Horizontal Distance (60 percent arm length)		

Height (cm)	Weight (kg)

CHAPTER 2: GLENOHUMERAL AND SCAPULOTHORACIC MOTION DURNING FUNCTIONAL REACHING TASKS IN WOMEN WITH HISTORY OF BREAST CANCER AND HEALTHY AGE-MATCHED CONTROLS

ABSTRACT

Background: Common medical management for breast cancer (BrCa) most often includes lumpectomy and radiation (LR) or mastectomy and reconstruction (MR). Due to these procedures involving the shoulder, it is not surprising that some women experience shoulder motion problems. However, the long-term effect that BrCa treatments (LR and MR) have on glenohumeral (GH) and scapulothoracic (ST) motions during functional tasks is not well understood.

Purposes: 1) determine differences in GH and ST motion between women with and without a BrCa during functional tasks; 2) determine the effect of different breast cancer treatments (LR and MR) on GH and ST motion.

Subjects: 30 women with BrCa (mean age ± SD = 52.7 ± 10.8 yrs.; mean time since surgery ± SD = 2.4 ± .9 yrs.; LR n = 20) and 30 women without BrCa (mean age ± SD = 53.8 ± 10.9 yrs.)

Methods: ST and GH kinematic data were collected using an electromagnetic device during 3 functional tasks (un-weighted overhead reaching, weighted overhead reaching, hair combing). Separate one-way multivariate analysis of variance (MANOVA) were conducted to determine whether differences existed between groups ($p < .05$).

Results: There were no significant differences in GH and ST motion between women with and without BrCa or between those with different medical management (LR, MR).

Discussion: Failure to find group differences in motion may be due to the fact that women in our study were relatively high functioning and recovered from their medical management. Additionally, the majority of women in our study were previously educated on a home exercise program (73.3%) and attended physical therapy (56.7%).

Conclusions: A lack of significant differences in ST and GH range of motion between women with and without a BrCa suggests that the women in our study had sufficient range of motion to accomplish the functional tasks.

INTRODUCTION

The lifetime probability for a woman developing breast cancer is 1 in 8.[1] Currently over 200, 000 women are diagnosed with breast cancer each year in the United States.[2] An estimated 3.1 million women with a history of breast cancer reside in the United States, and this number is estimated to rise to 3.9 million by 2024.[2] Due to improvements in the medical management of breast cancer, the overall 5-year relative survival rate has improved from 75% in 1975 to 90% between 2003 and 2009.[2] Although survival has improved, many woman experience shoulder and arm problems as a result of breast cancer treatment.[3] Shoulder and arm problems have been shown to be associated with activity limitations, participation restrictions, and reduced health related quality in women with a history of breast cancer.[4,5]

Treatment for breast cancer includes surgery, radiation, chemotherapy, or hormonal therapy. Because of surgery and radiation to anatomical structures involving the shoulder, it is not surprising that women experience shoulder and arm problems that impact the use of their upper extremity for functional activities.[6] Up to 67% of women have reported impaired shoulder motion after treatment, including women who undergo less extensive surgical procedures such as lumpectomy and sentinel lymph node biopsy (SLNB).[3,7] Although impaired shoulder motion is a well-documented problem[3,7], the majority of investigations focused on the amount of shoulder motion (i.e. flexion, abduction) represented by motion of the humerus with respect to the trunk (humerothoracic motion). However, shoulder motions consist of a complex interaction between glenohumeral and scapulothoracic joints. Proper glenohumeral and scapulothoracic motion is important for ensuring proper alignment between the humeral head and glenoid fossa, as well as the size of the subacromial space and contact area of the humerus with the posterior superior glenoid.[8-10]

Impaired glenohumeral and scapulothoracic motion have been found in individuals with shoulder pain and various musculoskeletal pathologies including rotator cuff disease.[8,9,11-13] Rotator cuff disease is a common shoulder pathology in the general population [14], and is thought to be a significant source of shoulder pain in women with a history of breast cancer.[6,15,16] The etiology of rotator cuff disease is multi-factorial with mechanistic theories suggesting intrinsic and extrinsic factors. Intrinsic factors refer to changes within the tendon due to aging, avascularity, macrotrauma, repetitive micro-trauma, and tension overload.[17-20] Extrinsic factors refer to mechanical compression of the tissues caused by elements outside of the rotator cuff tendon(s).[17-20] Impaired glenohumeral and scapulothoracic motion are reported extrinsic factors.[10,21]

Investigators have recently shown that women with a history of breast cancer demonstrate impaired scapulothoracic motion post-operatively when compared to women without a history of breast cancer.[22-25] However, two of these three investigative groups only included women who had undergone breast cancer surgery at least 12 months previously.[22-25] Therefore, little is known about the long-term effect that breast cancer treatments have on scapulothoracic motion. Additionally, the women included in these studies received a broad range of breast cancer treatments (i.e. mastectomy with and without radiation; wide local excision with or without radiation to axilla).[23-25] Radiation therapy has been shown to alter collagen synthesis[26-28], and cause soft tissue fibrosis affecting the flexibility of tissues within the radiation field contributing to impaired motion.[27-30] Breast reconstruction is a common breast cancer treatment option for women who undergo mastectomy.[2] One investigative group excluded women if they underwent breast reconstruction.[24,25] It is unclear if women who underwent breast reconstruction in the studies were included or not. Finally, scapulothoracic motion was measured as women raised and lowered their arms while performing a constrained task (i.e. moving in a specified plane of motion such as sagittal, scapular, or frontal). Overhead functional activities typically are not constrained to specific planes of motion[31,32], and scapulothoracic motion has been shown to differ between constrained tasks and functional activities in a healthy population.[33] Currently little is known about the impact of breast cancer treatments on scapulothoracic motion during functional activities. Thus, the first purpose of this study was to determine whether differences in glenohumeral and scapulothoracic motion existed between women with and without a history of breast cancer during functional tasks. The second purpose of this study was to determine the effect that different breast cancer treatments (lumpectomy and radiation, and mastectomy with breast reconstruction) have on glenohumeral and scapulothoracic motion during functional reaching tasks. We hypothesize that: 1) women with a history of breast cancer will demonstrate impairments in GH and ST motion during functional reaching tasks compared to women without a history of breast cancer treatment, 2) women with a history of lumpectomy and radiation will demonstrate greater impairments in motion during functional reaching tasks when compared to women treated with mastectomy and reconstruction, and 3) women with a history of mastectomy and reconstruction will demonstrate impairments in motion during functional reaching tasks compared to women without a history of breast cancer treatment.

METHODS

Subjects

Women between the age of 30 and 75 years, with and without a history of breast cancer, were recruited from the Greater Philadelphia area through personal contact, flyers, media advertisement, local oncologist offices, and local physical therapy clinics, to participate in the study that was approved by the university institutional review board (See Figure 1 for the flow diagram of subject recruitment and enrollment through different phases of the study). All subjects provided informed consent prior to participating in the study. Two groups of women with a history of breast cancer were recruited. Group 1 consisted of women who underwent mastectomy and immediate breast reconstruction (implant or autologous tissue). Women in this group were excluded if they had surgery within the previous 3 months (i.e. breast revision, nipple reconstruction), radiation, or a latissimus dorsi breast reconstruction. Women who had latissimus dorsi reconstructions were excluded because it is a breast reconstruction option that involves a shoulder muscle other than the pectoralis major, which raised concerns that women may present with different altered patterns of motion. Group 2 consisted of women with a history of breast cancer treatment that included lumpectomy and radiation. Women in Group 2 were excluded if they had a history of partial breast radiation or brachytherapy, or had radiation within the past 3 months. All women with a history of breast cancer must have undergone either sentinel lymph node biopsy (SLNB) or axillary lymph node dissection (ALND) and be 1-5 years post-surgery. Any woman in Group 1 or 2 was excluded if they had a history of shoulder pain prior to breast cancer treatment that required medical attention. Woman without a history of breast cancer were excluded if they had a history of shoulder pain that required them to seek medical care. All women who were unable to reach overhead, had an allergy to adhesive material, or had a history of any medical condition affecting the arms (i.e. fracture, stroke, cervical myopathy) were excluded. We attempted to match women with a history of breast cancer to women without a history of breast cancer by age (+/- 5 years) and body mass index (BMI) (+/- 3).

A total of 60 women participated in the study (10 mastectomy and reconstruction, 20 lumpectomy and radiation, and 30 without history of breast cancer). Descriptive statistics and clinical characteristics can be found in Table 1. There were no significant differences in age, BMI, race or amount of physical activity per week between groups (Table 1). Women with a history of breast cancer reported higher shoulder pain, lower satisfaction and decreased function compared to women without a history of breast cancer (Table 1).

Instrumentation

Continuous kinematic data were collected by an electromagnetic tracking system (Liberty™, Polhemus, Colchester, Vermont) at a sampling frequency of 120Hz per sensor. The validity of electromagnetic tracking systems for measuring scapulothoracic motion has been established.[34,35] Double sided tape, Velcro, and thermoplastic cuffs were used to secure sensors to the subjects in the following locations: sternum just inferior to the sternal notch; left and right scapula via means of a custom made scapular jig[34]; and, left and right humerus by means of a humeral cuff[36].

Procedures

Descriptive data were collected including age (years), height (cm), weight (kg), and hand dominance. All women completed questionnaires addressing self-report of shoulder pain and disability (Penn Shoulder Score) and average amount of physical activity per week (Paffenbarger Physical Activity Questionnaire). The following clinical characteristics were collected on women with a history of breast cancer: side affected, time since surgery (days), type of surgery (mastectomy or lumpectomy, SLNB or ALND), chemotherapy (yes/no), radiation (yes/no), history of physical therapy (yes/no and number of visits), and home exercise program instruction (yes/no and adherence). Women with a history of breast cancer also completed two additional questionnaires; fear of physical activity/exercise (Fear of Physical Activity/Exercise Scale-Breast Cancer) and health related quality of life (Functional Assessment of Cancer therapy-Breast Cancer + 4).

Upon completing the questionnaires kinematic sensors were placed on the previously described locations, and bony landmarks on the thorax, scapula, and humerus were digitized to create local body reference frames.[37,38] Kinematic data were collected as women stood in their natural relaxed posture and while performing 5 repetitions of unilateral un-weighted overhead reaching, weighted overhead reaching (0.91 kg), and simulated hair combing. For all trials, subjects were instructed to stand in their natural upright position and perform motions, as they would do on a normal basis. Practice trials were allowed to be sure subjects understood the tasks they were asked to perform.

Overhead reaching tasks required women to move their hand from a shelf in front of them to an overhead shelf and back. Shelf height was normalized using shoulder height and arm length anthropometric data from each woman.[33] Shoulder height was measured in standing as the distance from the anterior aspect of the acromion process to the ground. With the subject seated, arm at their side, and elbow extended, arm length was measured as the distance from the anterior aspect of the acromion process to the tip of the middle finger.[33] The bottom shelf was positioned at a height equal to 50% of arm length below shoulder height. The top shelf was positioned at a height equal to 50% of arm length above shoulder height. The horizontal distance from the shelf to the subject was equal to 60% of the subject's arm length.

Kinematic Data Reduction

Digitized boney landmarks, establishment of local coordinate systems, and description of scapulothoracic, glenohumeral, and humerothoracic motion generally followed the recommendations of The International Society of Biomechanics.[38] The position and orientation of the scapula relative to thorax (scapulothoracic) were described as 3 scapular and 2 clavicular rotations. Scapular rotations were described using an Euler angle sequence (z, y', x''), where scapular internal/external rotation occurred about the vertically oriented z-axis, upward/downward rotation occurred about the anteriorly oriented y-axis, and anterior/posterior tilt occurred about the laterally oriented x-axis. Motions of the clavicle with respect to the thorax were not measured directly, but were derived from boney landmarks on the sternum and scapula.[34,39] These motions consisted of clavicular elevation/depression (representing scapular superior/inferior translation) and clavicular protraction/retraction (representing scapular anterior/posterior translation).[34,39] Motions of the humerus relative to the scapula (glenohumeral) were described as glenohumeral elevation, adduction/abduction, and internal/external rotation using y, x', z'' Cardan angles. An Euler angle sequence of z, y', z'' was used to describe motions of the humerus relative to the thoracic (humerothoracic), which were defined as humerothoracic adduction/abduction, elevation/depression, and internal/external rotation. After data were collected, a linear interpolation program was used to obtain scapulothoracic and glenohumeral data at 5° increments of humerothoracic elevation.

Variables

Range of motion

Resting scapulothoracic (ST) and glenohumeral (GH) positions were determined from kinematic data while women stood in their naturally relaxed posture. The common maximum humerothoracic elevation angle amongst subjects across tasks was 85°. The amount of ST and GH motion at rest was subtracted from the amount of ST and GH motion at 85° humerothoracic elevation, and the resultant value was defined as ST and GH range of motion. The mean ST and GH range of motion from trials 2-4 of each task was used for subsequent analysis.

Data Analysis

Statistical analyses were performed using SPSS Version 23 (IBM Corporation, Armonk, NY). Separate one-way multivariate analysis of variance (MANOVA) were conducted to determine if differences in ST and GH range of motion existed between women with and without a history of breast cancer during overhead reaching and combing hair tasks. Significance levels were set at .05.

In order to determine the effect that different breast cancer treatments (lumpectomy and radiation, and mastectomy with breast reconstruction) have on ST and GH motion, separate one-way multivariate analysis of variance (MANOVA) were conducted to determine whether differences existed between the two groups of women with history of breast cancer and women without history of breast cancer for the overhead reaching and combing hair tasks. Significance levels were set at .05. Because of the unequal number of women treated with mastectomy/reconstruction (n = 10), lumpectomy/radiation (n = 20), and women without a history of breast cancer (n = 30), we performed the statistical analyses using data from an equal number of women within each group (10 per group). Subjects in the lumpectomy/ radiation and control group were selected to ensure that comparison was made within the same age range (30-50 years or 50+ years) and BMI category (normal, overweight, obese). The involved side in women with a history of breast cancer was matched by hand dominance with the appropriate side in women without a history of breast cancer. Descriptive statistics and clinical characteristics for these women can be found in Table 2.

RESULTS

Mean and standard deviations for ST and GH range of motion variables comparing women with and without a history of breast cancer can be found in Table 3. Results of the multivariate analysis of variance revealed no significant differences in ST or GH range of motion between women with (n = 30) and without (n = 30) a history of breast cancer (Table 4).

Mean and standard deviations for ST and GH range of motion variables comparing women treated with mastectomy/reconstruction, lumpectomy/radiation, and women without a history of breast cancer can be found in Table 5 and 6. Results of the multivariate analysis of variance revealed no significant differences in ST or GH range of motion between women treated with mastectomy/reconstruction (n = 10), lumpectomy/radiation (n = 10), and women without a history of breast cancer (n = 10) (Table 7).

DISCUSSION

Women with and without history of breast demonstrated similar amounts of movement during overhead and hair combing tasks. On average, the scapula upwardly rotated and posteriorly tilted while the clavicle elevated and retracted (Table 3). Minimal scapular internal/external rotation occurred (Table 3). With respect to GH motion, the humerus elevated, abducted, and externally rotated respect to the scapula during the functional tasks performed in this study (Table 3). These movement patterns are consistent with previously published studies that reported the contributions of GH and ST motion during similar functional tasks in healthy individuals.[32,33,40]

Findings from our study did not reveal differences in ST and GH motion between women with or without history of breast cancer or women who underwent lumpectomy/radiation, women who had mastectomy/reconstruction, and women without a history of breast cancer. Although our results are in line with those reported by Harrington et al. 2011[41], our findings are not consistent with the majority of other studies that have investigated ST motion in women with history of breast cancer.[22-25] These differences may be due, in part, to different study methodologies. We elected to investigate ST motion during functional tasks while previous studies[22-25] investigated ST motion during constrained tasks. Constraining tasks to a specific plane of humeral elevation reduces the variability of motion between subjects. In our study, the average plane of elevation at our common maximal humerothoracic elevation angle (85°) was 45.6 ± 12.3°, 42.9 ± 12.5°, and 49.0° ± 12.9° during un-weighted reaching, weighted reaching, and hair combing tasks respectively. Differences in ST motion have been reported between planes of humeral elevation[35], and variability in elevation plane suggests similar motions were not being performed between subjects. Additionally, our subjects, on average, raised their arms slightly anterior to the scapular plane. Previous studies found differences in ST motion during humeral elevation in the coronal and scapular plane[22-25,41]; however no differences in ST motion have been found during humeral elevation performed in the sagittal plane[23], which is anterior to scapular plane motion.

Conflicting results between our study and other studies may also be due to differences in how ST motion was defined. We elected to investigate ST range of motion, which we defined as scapular position at a common maximum humerothoracic elevation angle minus resting scapular position. This approach focuses on the movement of a subject' s scapula rather than posture (absolute position).[42] Borstad and Szucs 2011[22] analyzed ST motion at select humerothoracic angles (30°, 60°, 90°, and 120°) without subtracting resting values. Crosbie et al. 2010[23] defined ST motion by subtracting resting position from ST position at various positions of humeral elevation (0°, 30°, 60°, and 90° with respect to the global coordinate), while we analyzed ST motion at 85° of humeral elevation with respect to the thorax. We analyzed ST at motion at a humeral elevation angle respect to the trunk because thoracic motion was not constrained in our study and the amount of scapular motion that occurs during overhead reaching is dependent on the amount of humeral elevation respect to the trunk subjects perform.[31,35,39] Finally, Shamley et al. 2009 and 2014[24,25] analyzed data that were calculated by subtracting ST position of the unaffected side from the affected side. This approach may be limited by some women with a history of breast cancer demonstrating impaired shoulder range of motion on the unaffected side after surgery and radiation.[43]

Three of five previous studies on ST motion in women with a history of breast cancer included women who were either 2, 6, or 12 months post-surgery.[22,23,41] Women in our study were 1-5 years post-surgery (mean time since surgery: 2.4 ± .9 yrs.). Studies have shown that the prevalence of impaired shoulder motion decreases with time.[3,44] In two studies, by the same investigative group that included women who were more than 12 months post-surgery, women who underwent mastectomy may have also received radiotherapy to their axilla.[24,25] This cohort was not included in our study because we chose to include two current, most common treatment options (lumpectomy and radiation or mastectomy and reconstruction) for stage I and II breast cancers, which account for the majority of breast cancers.[1,45] Collectively, our subjects were further out from surgery and received less extensive breast cancer treatment than subjects in the majority of other studies.[3,22-25,41] This suggests that the probability of women experiencing shoulder motion problems was lower in our study.

Failure to find group differences in motion may also be because of the fact that women in our study were relatively high functioning (Table 1). Review of the responses on the Penn Shoulder Score revealed that items that were similar to the tasks women performed in our study showed only 6 out of 30 women with a history of breast cancer reported at least “some difficulty” related to combing hair (item 5). Seven out of 30 women with history of breast cancer reported at least “some difficulty” with reaching a shelf above head (item 14), and 8 out of 30 reported at least “some difficulty” with placing a soup can (1-2 lb.) on a shelf overhead (item 15). Not a single woman treated with mastectomy and reconstruction reported difficulty with combing hair, reaching a shelf, or placing a soup can overhead. Additionally, only 46.7% of women with history of breast cancer reported experiencing shoulder pain with the average pain level being 26.1 ± 5.8 (30 indicates no pain) as measured by the Penn Shoulder Score-Pain Subscale. Women experiencing low shoulder pain and disability in our study may be due to the fact that 73.3% reported being educated on a home exercise program, which women reported being approximately 65.9% adherent to, and 56.7% reported attending physical therapy for an average of 7.5 visits. Home exercise program education and performance may also have contributed to the lack of motion differences between these groups. This point needs to be systematically examined in prospective studies.

Lack of significant differences between women with and without history of breast cancer and women treated with mastectomy/reconstruction, lumpectomy/radiation, and women without a history of breast cancer may also be secondary to our small sample size and low statistical power (power < .49 for two group comparison and power < .39 for three group comparison). An a-priori power analysis (GPower 3.1) revealed that a total sample size of 67 subjects was needed to achieve power equal to .80, alpha of .05, for 3 groups with 8 measurements anticipating a 5° difference between groups with a standard deviation of 15° and a correlation of .40 among variables. It should be noted that effect sizes associated with group differences in our study were small with the largest being for clavicular elevation during hair combing (partial eta squared = 0.10). Additionally, the largest group mean difference for ST and GH motion was 3.8° of posterior tilt during weighted overhead reaching and 8.2° of GH adduction during un-weighted overhead reaching (Table 5), respectively. Even if enough subjects were recruited to achieve power of .80, these differences in ST and GH motion have questionable meaningfulness as they fail to exceed minimal detectable change 95% ($MDC_{95\%}$) values previously established in our lab ($MDC_{95\%}$ for ST posterior and GH adduction 4.4° and 8.6°, respectively).

Although we did not find group differences in the total amount of ST or GH motion during the overhead activities, we did notice, on several occasions, that the manner in which women with a history of breast cancer performed the overhead movements looked different from how women without a history of breast cancer performed the movements. Women with history of breast cancer appeared to have excessive scapular motion and/or lack of smooth scapular and humeral motion, which suggests that women with history of breast cancer may have impaired movement coordination between the scapula and humerus (scapulohumeral coordination). Other statistical approaches such as continuous motion angle-angle and coupling angle-movement cycle graphs with predication bands may prove to be useful for better understanding the effect of breast cancer treatments on scapulohumeral coordination.[42]

CONCLUSION

Although impaired shoulder motion is well documented in earlier stages of recovery (up to 12 months) in women who have been treated for breast cancer[3], we did not find differences in ST and GH range of motion between women with (over 12 months post op) and without a history of breast cancer during the performance of three overhead functional reaching tasks. This suggests that the women in our study who were treated for breast cancer had sufficient range of motion to accomplish the functional tasks performed in our study. Further research is needed to determine whether these women demonstrate impaired ST and GH motion during more demanding tasks such as heavy lifting or repetitive reaching. Additionally, the impact of breast cancer treatment on scapulohumeral coordination is not well understood and warrants further investigation.

FIGURES AND TABLES

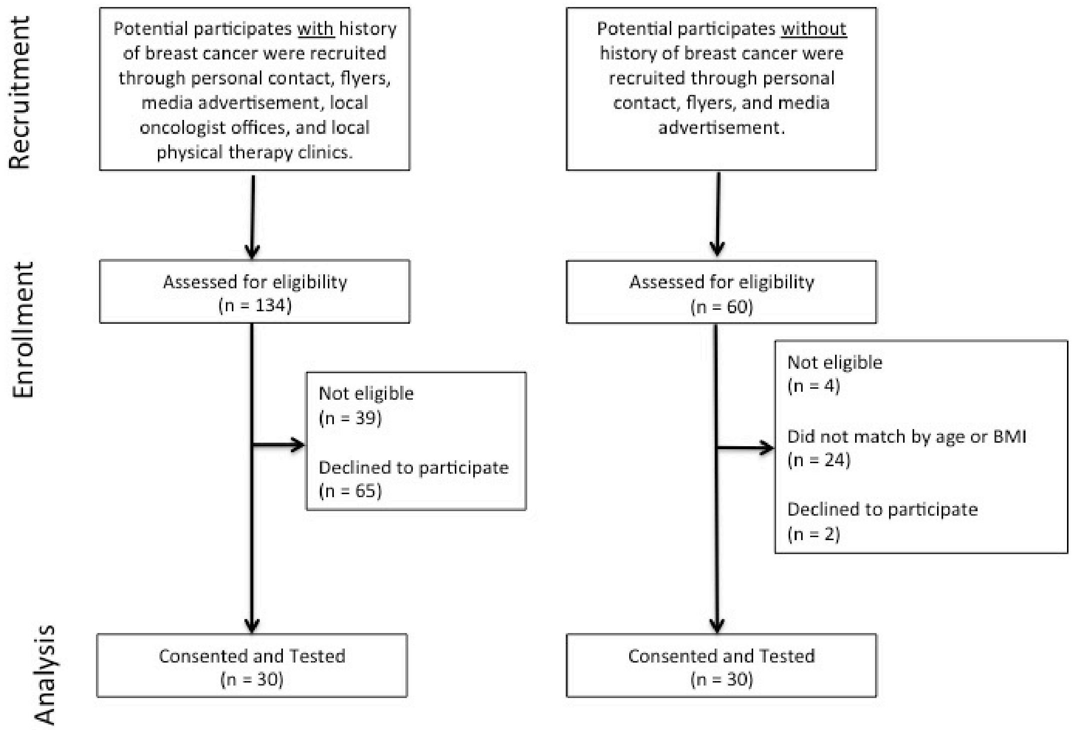

Figure 1: Flow diagram of subject recruitment and enrollment through different phases of the study

Table 1: Descriptive statistics for all subjects (n = 60)

	BrCa (n = 30)	Controls (n =30)	p values
Age (years) Mean ± SD	53.8 ± 10.9	52.7 ± 10.8	ns
BMI (kg/m^2) Mean ± SD	28.3 ± 6.1	29.1 ± 6.0	ns
Race (n)			
Caucasian	18	16	ns
African-American	10	14	
Asian	2	0	
Penn Shoulder Score			
Pain Subscale	26.1 ± 5.8	29.7 ± .9	$p < .05$
Satisfaction Subscale	7.9 ± 2.9	9.2 ± 1.4	$p < .05$
Function Subscale	51.2 ± 11.7	57.5 ± 4.4	$p < .05$
Total Score	85.3 ± 19.5	96.4 ± 5.4	$p < .05$
Paffenbarger Physical Activity Questionnaire (kcal/wk)	1596 ± 943	1913 ± 1562	ns
Type of breast cancer treatment (n)			
Lumpectomy/radiation	20		
Mastectomy/reconstruction	10		
Type of lymph node surgery (n)			
SLNB	25		
ALND	5		
Side affected (n)			
Dominant side	17		
Non-dominant side	13		
Time since surgery (days) Mean ± SD	893 ± 325		
Chemotherapy (n)			
Yes	12		
No	18		
FPAX-B Mean ± SD	9.7 ± 11.1		
FACT-B + 4 Mean ± SD	122.6 ± 22.0		
Educated on HEP (n)			
Yes	22		
No	8		
Attended physical therapy (n)			
Yes	17		
No	13		

BrCa: women with history of breast cancer treatment
ns: no significant difference between groups
FPAX-B: Fear of Physical Activity/Exercise Scale-Breast Cancer
FACT-B+4: Functional Assessment of Cancer therapy-Breast Cancer + 4

Table 2: Descriptive statistics for subjects (n= 30) matched by age and body mass index

	Controls (n =10)	LR (n =10)	MR (n =10)	p values
Age (years) Mean ± SD	50.5 ± 12.4	52.1 ± 6.2	49.6 ± 13.9	ns
BMI (kg/m^2) Mean ± SD	26.5 ± 5.2	26.9 ± 6.3	26.1 ± 6.7	ns
Penn Shoulder Score				
Pain Subscale	30 ± 0	25.5 ± 6.3	28.9 ± 1.7	$p < .05^{\#}$
Satisfaction Subscale	9.7 ± .9	7.3 ± 3.6	9.2 ± 1.2	ns
Function Subscale	58.8 ± 3.5	49.1 ± 11.5	57.3 ± 2.4	$p < .05^{\#, *}$
Total Score	98.5 ± 4.4	81.9 ± 20.4	95.4 ± 4.4	$p < .05^{\#}$
Paffenbarger Physical Activity Questionnaire (kcal/wk)	1826 ± 1911	1316 ± 610	2064 ± 433	ns
Time since surgery (days) Mean ± SD		931 ± 380	806 ± 310	ns
FPAX-B Mean ± SD		9.7 ± 11.9	7.6 ± 7.5	ns
FACT-B + 4 Mean ± SD		124.7 ± 24.4	127.1 ± 24.4	ns

LR: lumpectomy/radiation; MR: mastectomy/reconstruction
ns: no significant difference between groups
#: significant difference between controls and lumpectomy/radiation group
*: significant difference between lumpectomy/radiation group and mastectomy/reconstruction group
FPAX-B: Fear of Physical Activity/Exercise Scale-Breast Cancer
FACT-B+4: Functional Assessment of Cancer therapy-Breast Cancer + 4

Table 3: Scapulothoracic and glenohumeral motion (degrees) during un-weighted reaching, weighted reaching, and hair combing tasks for all subjects grouped by controls, women with history of breast cancer, and all subjects combined

		Un-weighted Reaching Mean (SD)			Weighted Reaching Mean (SD)			Hair Combing Mean (SD)		
		Controls (n = 30)	BrCa (n = 30)	Total (n = 60)	Controls (n = 30)	BrCa (n = 29)	Total (n = 60)	Controls (n = 30)	BrCa (n = 30)	Total (n = 60)
ST	IR/ER*	1.5 (4.5)	-0.6 (5.6)	0.4 (5.2)	0.9 (4.4)	-0.8 (5.7)	0.1 (5.1)	0.4 (4.5)	-0.6 (4.9)	-0.1 (4.7)
	UR	18.5 (5.3)	16.4 (3.7)	17.4 (4.6)	20.0 (5.6)	18.4 (3.7)	19.2 (4.8)	17.4 (5.4)	15.8 (4.5)	16.6 (5.0)
	PT	9.0 (5.8)	8.0 (5.9)	8.5 (5.8)	9.5 (6.2)	8.0 (5.9)	8.7 (6.1)	8.0 (5.1)	7.0 (4.8)	7.5 (4.9)
	CE	10.2 (4.3)	8.3 (5.1)	9.3 (4.7)	10.7 (4.5)	9.3 (5.2)	10.0 (4.9)	9.8 (3.7)	8.7 (3.9)	9.3 (3.8)
	CR	10.2 (5.7)	9.9 (5.9)	10.0 (5.7)	11.9 (6.2)	11.2 (5.8)	11.5 (5.9)	9.9 (4.1)	9.2 (4.2)	9.6 (4.1)
GH	Ele	57.0 (8.5)	58.5 (5.3)	57.7 (7.1)	55.3 (8.7)	56.5 (5.2)	55.9 (7.2)	59.1 (7.9)	59.9 (6.5)	59.5 (7.2)
	Add	-11.8 (10.4)	-16.1 (14.2)	-13.9 (12.6)	-8.9 (10.7)	-14.2 (15.2)	-11.5 (13.3)	-17.5 (11.5)	-18.7 (14.7)	-18.1 (13.1)
	ER	43.2 (15.7)	48.5 (11.6)	45.8 (13.9)	42.5 (15.5)	47.6 (10.8)	45.0 (13.5)	39.3 (15.9)	45.0 (14.1)	42.2 (15.2)

ST: scapulothoracic; GH: glenohumeral; IR: internal rotation; ER: external rotation; UR: upward rotation; PT: posterior tilt; CE: clavicular elevation; CR: clavicular retraction; Elv: elevation; Add: adduction; BrCa: women with history of breast cancer
*: positive value indicates more ST internal rotation

Table 4: Results of multivariate analysis of variance to determine differences between controls and women with history of breast cancer

	F value	df	p value
Un-weighted reaching	1.20	8, 51	.32
Weighted reaching	.914	8, 50	.51
Combing hair	.614	8, 51	.76

Table 5: Scapulothoracic and glenohumeral motion (degrees) during un-weighted reaching, weighted reaching, and hair combing tasks for 30 subjects matched by age and body mass index

		Un-weighted Reaching Mean (SD)			Weighted Reaching Mean (SD)			Hair Combing Mean (SD)		
		Controls (n = 10)	LR (n = 10)	MR (n = 10)	Controls (n = 10)	LR (n = 10)	MR (n = 10)	Controls (n = 10)	LR (n = 10)	MR (n = 10)
ST	IR/ER*	0.7 (3.5)	-1.6 (4.8)	-0.9 (7.1)	0.5 (3.3)	-1.2 (5.2)	-1.0 (7.3)	-1.0 (3.1)	-0.8 (5.3)	-1.3 (5.8)
	UR	18.6 (4.0)	17.9 (4.4)	16.1 (2.6)	20.1 (3.8)	19.5 (4.4)	18.0 (2.5)	19.4 (5.0)	17.0 (5.8)	16.0 (3.0)
	PT	8.6 (6.0)	7.9 (6.4)	5.2 (5.4)	9.2 (6.1)	8.0 (5.8)	5.4 (5.7)	7.0 (4.9)	6.1 (6.0)	5.3 (2.5)
	CE	9.7 (5.7)	10.1 (6.0)	7.0 (4.7)	9.9 (5.9)	10.7 (5.5)	7.9 (5.1)	9.2 (3.2)	9.9 (4.1)	7.4 (2.9)
	CR	11.2 (8.2)	10.8 (4.7)	9.9 (7.5)	12.3 (9.2)	11.4 (4.8)	11.0 (7.1)	11.2 (5.1)	9.8 (3.4)	8.7 (4.0)
GH	Ele	59.5 (10.1)	59.8 (4.8)	57.2 (6.2)	58.0 (9.5)	57.8 (4.4)	55.2 (5.8)	60.8 (11.7)	61.5 (5.3)	57.8 (7.3)
	Add	-12.0 (9.0)	-18.8 (15.5)	-20.1 (12.2)	-10.0 (10.3)	-17.2 (16.0)	-18.2 (13.0)	-21.1 (10.7)	-20.7 (13.8)	-22.2 (14.5)
	ER	46.4 (17.8)	50.3 (7.9)	51.7 (11.1)	46.0 (17.6)	48.6 (6.9)	50.7 (10.6)	43.8 (21.6)	48.3 (9.0)	46.7 (10.5)

ST: scapulothoracic; GH: glenohumeral; IR: internal rotation; ER: external rotation; UR: upward rotation; PT: posterior tilt; CE: clavicular elevation; CR: clavicular retraction; Elv: elevation; Add: adduction; LR: lumpectomy/radiation; MR: mastectomy/reconstruction
*: positive value indicates more ST internal rotation

Table 6: Scapulothoracic and glenohumeral motion (degrees) during un-weighted reaching, weighted reaching, and hair combing tasks for all subjects grouped by controls, women who underwent lumpectomy/radiation and women who underwent mastectomy/reconstruction

		Un-weighted Reaching Mean (SD)			Weighted Reaching Mean (SD)			Hair Combing Mean (SD)		
		Controls (n = 30)	LR (n = 20)	MR (n = 10)	Controls (n = 30)	LR (n = 20)	MR (n = 10)	Controls (n = 30)	LR (n = 20)	MR (n = 10)
ST	IR/ER*	1.5 (4.5)	-0.5 (4.9)	-0.9 (7.1)	0.9 (4.4)	-0.7 (4.9)	-1.0 (7.3)	0.4 (4.5)	-0.3 (4.5)	-1.3 (5.8)
	UR	18.5 (5.3)	16.5 (4.2)	16.1 (2.6)	20.0 (5.6)	18.6 (4.3)	18.0 (2.5)	17.4 (5.4)	15.7 (5.2)	16.0 (3.0)
	PT	9.0 (5.8)	9.3 (5.7)	5.2 (5.4)	9.5 (6.2)	9.3 (5.6)	5.4 (5.7)	8.0 (5.1)	7.8 (5.4)	5.3 (2.5)
	CE	10.2 (4.3)	9.0 (5.2)	7.0 (4.7)	10.7 (4.5)	10.0 (5.2)	7.9 (5.1)	9.8 (3.7)	9.4 (4.2)	7.4 (2.9)
	CR	10.2 (5.7)	10.0 (5.1)	9.9 (7.5)	11.9 (6.2)	11.3 (5.2)	11.0 (7.1)	9.9 (4.1)	9.5 (4.3)	8.7 (4.0)
GH	Ele	57.0 (8.5)	59.1 (4.8)	57.2 (6.2)	55.3 (8.7)	57.2 (4.9)	55.2 (5.8)	59.1 (7.9)	61.0 (5.9)	57.8 (7.3)
	Add	-11.8 (10.4)	-14.1 (15.1)	-20.1 (12.2)	-8.9 (10.7)	-12.1 (16.2)	-18.2 (13.0)	-17.5 (11.5)	-16.9 (14.8)	-22.2 (14.5)
	ER	43.2 (15.7)	46.8 (11.7)	51.7 (11.1)	42.5 (15.5)	46.0 (10.9)	50.7 (10.6)	39.3 (15.9)	44.1 (15.8)	46.7 (10.5)

ST: scapulothoracic; GH: glenohumeral; IR: internal rotation; ER: external rotation; UR: upward rotation; PT: posterior tilt; CE: clavicular elevation; CR: clavicular retraction; Elv: elevation; Add: adduction; LR: lumpectomy/radiation; MR: mastectomy/reconstruction
*: positive value indicates more ST internal rotation

Table 7: Results of multivariate analysis of variance to determine differences between controls, women treated with lumpectomy/radiation, and women treated with mastectomy/reconstruction that were matched by age and body mass index

	F value	df	p value
Un-weighted reaching	.698	16, 42	.78
Weighted reaching	.819	16, 42	.66
Combing hair	1.15	16, 42	.35

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CHAPTER 3: CLINICAL FACTORS ASSOCIATED WITH IMPAIRED SHOULER COMPLEX COORDINATION IN WOMEN WITH A HISTORY OF BREAST CANCER TREATMENT

ABSTRACT

Background: Impaired scapulohumeral coordination is believed to be a problem experienced by women after treatment of breast cancer (BC). Factors including pain, resting scapular alignment (RSA), tissue flexibility, strength, and lymphedema have been proposed to contribute to this problem, but limited research exists to support this notion.

Objective: 1) determine the proportion of women with BC who demonstrate impaired scapulohumeral coordination during overhead reaching; 2) identify clinical factors associated with impaired scapulohumeral coordination.

Design: Observational study

Methods: Scapular and humeral kinematic data and clinical measures of pain, RSA, tissue flexibility, strength and lymphedema were collected on 30 women with BC (mean age ± SD = 53.8 ± 10.9 yrs.) and 30 women without BC (mean age ± SD = 52.7 ± 10.8 yrs.). Angle-angle and relative motion graphs were created for 3 scapular and 2 clavicular rotations. Mean curves with 95% minimal detectable change bands (MDCB) were calculated using data from women without BC. Each woman with BC's curve was individually compared to the mean curve and MDCB. Women with BC were classified as having normal (curve fell within MDCB) or impaired scapulohumeral coordination (curve fell outside MDCB).

Results: Over 93% of women with BC demonstrated impaired scapulohumeral coordination for at least 1 scapular or clavicular rotation. Discriminant analysis revealed that clinical measures of pain, RSA, tissue flexibility, strength, and lymphedema were associated with impaired scapulohumeral coordination. Cross-validated classification showed that 43.4% to 73.3% of women were grouped correctly.

Conclusion: Clinical measures of tissue flexibility (ROM and pectoralis minor length) were associated with impaired scapulohumeral coordination across multiple scapular and clavicular rotations.

INTRODUCTION

Impaired shoulder girdle motion affects up to 67% of breast cancer survivors. Motion losses have been reported to range from 3°- 17° for flexion, 7°- 33° for abduction, 1°- 11° for external rotation, and 1°- 4° for internal rotation.[1-5] Although this problem is well documented[6,7], breast cancer survivors continue to experience shoulder girdle motion impairments years after treatment.[7-9] This long-term complication may be because women fail to discuss their shoulder problems with health care providers[10] or providers fail to prospectively screen for impairments contributing to a lack of referrals for women who may benefit from rehabilitation services.[11] Complications may also result from less effective rehabilitation interventions that stem from a poor understanding of mechanisms associated with impaired shoulder girdle motion in this population.

Shoulder girdle motion involves multiple bony segments (scapula, clavicle, and humerus). Investigators who have researched segmental contributions of shoulder girdle motion have found that women with a history of breast cancer demonstrate impaired scapulothoracic motion post-surgically when compared to their unaffected side, as well as when compared to women without a history of breast cancer.[12-15] Impaired scapulohumeral coordination amongst women with history of breast cancer is likely as these women frequently experience shoulder girdle soft tissue pain[6,7], decreased shoulder girdle muscle strength[6,7], decreased tissue flexibility[16], altered resting scapular alignment[17,18], and lymphedema.[6,19] These impairments are not surprising as breast cancer treatments (surgery and radiation) directly affect anatomical structures of the shoulder girdle.[20] Although women with a history of breast cancer treatment have been shown to experience a number of impairments believed to impact scapulohumeral coordination, the association of these impairments with altered scapulohumeral coordination has yet to be supported.

The majority of investigators who found that women with a history of breast cancer demonstrate impaired scapulothoracic motion have focused on the position and orientation of the scapula on the thorax at select angles of humeral elevation (i.e. scapular position/orientation at 30°, 60°, and 90° of humerothoracic elevation).[12,13,21] While this approach suggests that altered movement may be present, the approach does not adequately capture the complex relationship between glenohumeral and scapulothoracic motion (scapulohumeral coordination) throughout the movement cycle. Continuous motion angle-angle graphs, relative motion graphs, and their respective predication bands have been recommended for better understanding scapulohumeral coordination.[22-24] Prediction bands represent movement variability, and can be used to determine if a movement pattern from a woman with a history of breast cancer is different than a population of women without breast cancer.[22] This approach allows investigators to assess the proportion of woman with a history of breast cancer who demonstrate impaired scapulohumeral coordination.

Studies designed to assess scapulohumeral coordination in women with a history of breast cancer are needed because many women experience activity limitations such as overhead reaching and hair combing.[8] These activities require proper scapulohumeral coordination in order to position the hand in space without subjecting the nueromusculoskeletal tissues of the shoulder girdle to potentially harmful stresses.[25-28] Furthermore, impaired scapulohumeral coordination has been associated with individuals demonstrating various shoulder pathologies including symptomatic rotator cuff disease.[29-33]

Rotator cuff disease is a common shoulder pathology in the general population[34], and is thought to be a significant source of shoulder pain in women with a history of breast cancer.[16,20,35] During upper extremity movements, glenohumeral and scapulothoracic motions are believed to influence humeral head and glenoid fossa alignment as well as the size of the subacromial space.[29,32,36] Impaired scapulohumeral coordination may lead to excessive stresses being placed upon tissues thereby increasing the risk for development of symptomatic rotator cuff disease.[36,37] A better understanding of scapulohumeral coordination in women with a history of breast cancer may provide evidence to explain why symptomatic rotator cuff disease is a significant problem in this population. Additionally, this information may highlight impairments to be screened for and addressed by rehabilitation professionals in order to reduce the risk of developing symptomatic rotator cuff disease.

Identifying impairments associated with impaired scapulohumeral coordination is important because rehabilitation professionals do not directly address altered scapulohumeral coordination, rather they attempt to address the mechanisms that are believed to be contributing to impaired scapulohumeral coordination. A better understanding of impaired scapulohumeral coordination and the underling variables associated with it will lead to evidence-based examination, intervention, and prevention techniques designed to maximize functional ability and reduce the risk for developing musculoskeletal-related shoulder pathologies in women who have been treated for breast cancer. Therefore, the purposes of this study were to: 1) determine the proportion of women with a history of breast cancer that demonstrate impaired scapulohumeral coordination during an overhead functional reaching task; and 2) identify clinical factors associated with impaired scapulohumeral coordination in women with history of breast cancer.

METHODS

Subjects

Women with and without a history of breast cancer between the ages of 30-75 years were recruited from the Greater Philadelphia area through personal contact, flyers, media advertisement, local oncologist offices, and local physical therapy clinics to participate in the study that was approved by the university institutional review board. (See Figure 1 for the flow diagram of subject enrollment and recruitment through different phases of the study). All subjects provided informed consent prior to participating in the study. Women with a history of breast cancer were eligible to participate if they: were treated with either mastectomy and immediate breast reconstruction, or lumpectomy and radiation; underwent either sentinel lymph node biopsy or axillary node dissection; and were 1-5 years post surgery. Women with history of breast cancer were excluded if they had a history of shoulder pain prior to breast cancer treatment. Women who underwent mastectomy and immediate breast reconstruction were excluded if they had a latissimus dorsi breast reconstruction, surgery within the previous 3 months (i.e. breast revision, nipple reconstruction), or radiation. Women who underwent lumpectomy and radiation were excluded if they had partial breast radiation or brachytherapy, or radiation within the past 3 months. Woman without a history of breast cancer were excluded if they had a history of shoulder pain that required them to seek medical care. All women who were unable to reach overhead, allergic to adhesive material, or had a history of any medical condition affecting the arms (i.e. fracture, stroke, cervical myopathy) were excluded. We attempted to match women with a history of breast cancer to women without a history of breast cancer by age (+/- 5 years) and body mass index (BMI) (+/- 3).

A total of 60 women participated in this study (30 women with and 30 women without a history of breast cancer). Descriptive data can be found in Table 1. One woman with history of breast was unable to perform weighted reaching due to increased shoulder pain; therefore, the number of women with a history of breast cancer for analysis of weighted reaching was 29.

Clinical Examination

Women with a history of breast cancer underwent a musculoskeletal and lymphedema assessment of the upper extremity. This was performed by the primary author who has 11 years of clinical experience working with survivors of breast cancer. Tests and measures included: self-report of shoulder pain intensity, active and passive shoulder range of motion, shoulder strength, pectoralis major and minor muscle length assessment, visual assessment of resting scapular alignment, and upper extremity limb volume. Summary of literature investigating the reliability and measurement error associated with these clinical shoulder measures along with intraclass correlation coefficient ($ICC_{(3, 2)}$), standard error of measurement (SEM) and minimal detectable change ($MDC_{90\%}$) values for pectoralis minor and major length assessment derived from repeated measurements performed on10 of the women with history of breast cancer treatment can be found in Appendix A.

Pain Intensity: Pain at rest and during arm motion was assessed with the 11-point Numeric Pain Rating Scale (0 = "no pain", 10 = "most imaginable pain").[38] The Pain Subscale of the PENN Shoulder Score[39] was also used to assess shoulder pain. The pain subscale is based on 30 points, where subjects rate their level of pain at rest, with normal activities, and with strenuous activities using an 11-point numeric rating scale.[39]

Active and Passive Shoulder Range of Motion (ROM): Active and passive shoulder ROM (forward elevation (FE), abduction (ABD), external rotation (ER) at 0° ABD, external rotation at 90° ABD) were measured bilaterally with a universal goniometer using standardized patient positioning.[40] Active and passive shoulder internal rotation (IR) ROM were measured as the vertebral level reached by the thumb when the hand was placed behind and up the back as far as possible.[41] Each measurement was performed once.

Shoulder Strength: Bilateral isometric shoulder force production was measured using a hand-held dynamometer (Lafayette Instrument Company, Lafayette, Indiana). The following measures were obtained: ER force at 0° ABD with neutral internal/external rotation, IR force at 0° ABD with neutral internal/external rotation, and FE in the plane of the scapula at 45° of elevation. For these tests, the subject was seated in an upright position. The dynamometer was placed proximal to the wrist at the level of the ulnar styloid process for ER and IR, and the distal humerus for FE. For each measurement, a "make test" was performed. This test requires the examiner to hold the dynamometer in the desired testing position while the subject is asked to exert maximal force against the dynamometer for 5 seconds.[41,42] Each measurement was performed three times, and the average of the three trials was calculated. Non-normalized and normalized (force/ body weight (kg)) data were used for subsequent analysis.

Pectoralis Major Muscle Length: Our approach for assessing pectoralis major muscle length was based on a simulation model.[43] This model demonstrated pectoralis major muscle strains on the order of 31-33% when the shoulder was abducted to 90° and externally rotated, and 22-55% when the shoulder was in full flexion.[43] Bilateral shoulder flexion, and ER with the arm positioned at 90° ABD were measured using a universal goniometer while subjects were positioned supine. Two measurements for each motion were taken, and the average of the two measurements was calculated. Pectoralis major muscle length was defined as a composite score calculated by the sum of the flexion and ER values.

Pectoralis Minor Muscle Resting and Elongated Length: A PALpation Meter (PALM) caliber was used to measure bilateral pectoralis minor muscle resting and elongated length. Pectoralis minor muscle resting and elongated length was defined as the distance from the coracoid process to the inferior aspect of the 4th rib just lateral to (1 finger width) the sternal-costal junction.[44] For resting length, subjects stood in their normal relaxed posture while the measurement was taken. For elongated length, subjects fully elevated and retracted their scapula and held this position while the measurement was taken. Each measurement was performed twice. The average of the two trials was normalized by clavicle length (cm), sternal length (cm) and height (cm).

Resting Scapular Alignment: Subjects stood in their natural relaxed posture while resting alignment of each scapula on the thorax was visually assessed from posterior, lateral, and anterior views to determine whether or not: 1) the scapula lay flat against the upper back, 2) the vertebral border of the scapula was parallel to the thoracic spinous processes 3) the clavicle was either horizontal or elevated by 6°-10° at the acromial end, and 4) the acromion was forward respect to the center of the thorax. Each of the four criteria was rated as normal or mal-aligned (subtle or obvious). A final rating for each scapula was defined as normal (all normal ratings or 1 subtle rating), subtle (2 or more subtle ratings), or obvious (at least 1 obvious rating).

Upper extremity limb volume: A tape measure was used to obtain circumferential measurements at the wrist (ulnar styloid process), as well as 4 cm intervals from the wrist to the shoulder. Total limb volume was calculated by adding the volumes of the truncated cones between these points.[45] For woman with a history of breast cancer treatment, the percent difference between limbs was calculated by the following formula: (limb volume affected-limb volume unaffected)/limb volume unaffected.

Kinematic Data

Instrumentation

An electromagnetic device (Liberty™, Polhemus, Colchester, Vermont) was used to collect continuous kinematic data of the scapula and humerus during the performance of two functional tasks. Kinematic data were collected at a sampling frequency of 120Hz per sensor. Double sided tape, Velcro, and thermoplastic cuffs were used to secure five sensors to the subjects in the following locations: sternum just inferior to the sternal notch; left and right scapula via means of a custom made scapular jig[46]; left and right humerus by means of a humeral cuff.[47]

Functional Tasks

Kinematic data were collected while women stood in their natural relaxed posture as well as during the performance of 5 repetitions of unilateral un-weighted and weighted (0.91 kg) overhead reaching. For all trials, subjects were instructed to stand in their natural upright position and then perform motions as they would do on a normal basis. Practice trials were allowed to be sure subjects understood the motions they were asked to perform.

Overhead reaching tasks required women to move their hand from a shelf in front of them to an overhead shelf and back. Shelf height was normalized using shoulder height and arm length anthropometric data from each woman.[25] Shoulder height was measured in standing as the distance from the anterior aspect of the acromion process to the ground. With the subject seated, arm at their side, and elbow extended, arm length was measured as the distance from the anterior aspect of the acromion process to the tip of the middle finger.[25] The bottom shelf was positioned at a height equal to 50% of arm length below shoulder height. The top shelf was positioned at a height equal to 50% of arm length above shoulder height. The horizontal distance from the shelf to the subject was equal to 60% of the subject's arm length.

Kinematic Data Reduction

Digitized boney landmarks, establishment of local coordinate systems, and description of scapulothoracic, glenohumeral, and humerothoracic motion generally followed the recommendations of The International Society of Biomechanics.[48] The position and orientation of the scapula relative to thorax (scapulothoracic) were described as 3 scapular rotations and 2 clavicular rotations. Scapular rotations were described using an Euler angle sequence (z, y', x''), where scapular internal/external rotation occurred about the vertically oriented z-axis, upward/downward rotation occurred about the anteriorly oriented y-axis, and anterior/posterior tilt occurred about the laterally oriented x-axis. Clavicular motions with respect to the thorax were not measured directly, but were derived from boney landmarks on the sternum and scapula.[46,49] These motions consisted of clavicular elevation/depression (representing scapular superior/inferior translation) and clavicular protraction/retraction (representing scapular anterior/posterior translation).[46,49] Motions of the humerus relative to the scapula (glenohumeral) were described as glenohumeral elevation, adduction/abduction, and internal/external rotation using y, x', z'' Cardan angles. An Euler angle sequence of z, y', z'' was used to describe motions of the humerus relative to the thoracic (humerothoracic), which were defined as humerothoracic adduction/abduction, elevation/depression, and internal/external rotation.

After data were collected, a linear interpolation program was used to obtain scapulothoracic and glenohumeral data at 5° increments of humerothoracic elevation. Data were filtered [zero lag, 4^{th} order Butterworth filter (8Hz)] using a custom LabView program and resampled (101 points) across a common range of humerothoracic elevation that was performed during trials 2 – 4 of the overhead reaching tasks. Data were then averaged and used to create angle-angle graphs and relative motion graphs that represented the pattern of motion during the task. Angle-angle graphs (Figure 2) were created for scapular and clavicular rotations by plotting scapular or clavicular motion on the Y-axis and humerothoracic elevation on the X-axis. Relative motion graphs (Figure 3) were created by plotting percent of movement on the X-axis (0-50% of movement represents the raising phase and 51-100% represents the lowering phase) and coupling angles on the Y-axis. Coupling angles were derived for scapular internal rotation (IR), upward rotation (UR), and anterior tilt (AT), as well as clavicular elevation (CE), and protraction (CP) relative to glenohumeral elevation (Appendix B). Coupling angles quantify the relative amount of motion between two bony segments and provide information relative to intersegment coordination. Coupling angles range from -90° to 90°. The sign of the coupling angle indicates whether segments are moving in the same (+) or different (-) direction, while the magnitude provides information about the amount of relative motion that occurs between segments. A coupling angle of 45° indicates 1:1 motion between segments. A coupling angle greater than 45° indicates more motion of the proximal segment (scapula or clavicle) relative to the distal segment (humerus), while a coupling angle less than 45° indicates more motion of the distal segment.

Scapulohumeral Coordination

In this study scapulohumeral coordination was represented by three scapular rotations (UR, IR, and AT) and two clavicular rotations (CP and CE). For each rotation typical averaged angle-angle and relative movement pattern profile were created from the group of women without history of breast cancer. Ninety-five percent minimal detectable change bands ($MDCB_{95\%}$) were derived around the control group's mean curves by calculating the minimal detectable change value at each data point (Appendix B). Once this step was completed, data from each woman with a history of breast cancer were individually compared to the mean curve and $MDCB_{95\%}$ derived from the group of women without breast cancer (Figure 4). A woman with history of breast cancer was considered to have impaired scapulohumeral coordination if her curve fell outside the $MDCB_{95\%}$ for greater than 10% of the movement during the raising or lowering phases of arm movement. Women with a history of breast cancer were classified as having normal movement patterns (curve fell within $MDCB_{95\%}$), a movement pattern with more scapular or clavicular motion (curve fell outside the upper limit of the $MDCB_{95\%}$), or movement pattern with less scapular or clavicular motion (curve fell outside the lower limit of the $MDCB_{95\%}$) (Figure 4).

Data Analysis

The percentage of women with a history of breast cancer that demonstrated each scapulohumeral coordination pattern (normal, more, or less motion) was calculated. In order to determine the association between clinical variables and impaired scapulohumeral coordination, we first used multiple one-way analyses of variance, or Kruskal-Wallis tests to determine whether there was a significant difference in shoulder range of motion, shoulder strength, pectoralis major length, pectoralis minor length, resting scapular alignment and upper extremity limb volume between women classified as having normal, more, or less motion for each scapular (i.e. IR, UR, AT) and clavicular (i.e. CE and CR) rotation. Next, stepwise discriminant analyses were used to identify clinical variables that could classify women as having normal, more, or less scapular or clavicular motion patterns ($p < .05$). Separate discriminant analyses were performed for each scapular and clavicular rotation and the two functional tasks. Clinical variables identified by results of the one-way analyses of variance, or Kruskal-Wallis tests to be significantly different between women with normal, more, or less scapular or clavicular motion were included as potential predictors in the discriminant analyses. Since we did not wish to exclude a variable that may be a useful predictor, a more liberal significance level ($p < .10$) was used to identify variables entered into the discriminant analysis.[50]

RESULTS

Proportion of Women with Impaired Scapulohumeral Coordination during Un-weighted and Weighted Reaching Tasks

1. ANGLE-ANGLE GRAPH ANALYSES

For un-weighted reaching, 10% of women with a history of breast cancer were classified as having impaired scapulohumeral coordination (i.e. a movement pattern with more or less scapular or clavicular motion) across all scapular and clavicular rotations. Only 3.3% of women were classified as having normal scapulohumeral coordination across all scapular and clavicular rotations. The percentage of women with history of breast cancer that were classified with impaired scapulohumeral coordination for 1, 2, 3, or 4 scapular/clavicular rotations during un-weighted reaching was 40%, 20%, 20% and 6.7%, respectively.

For weighted reaching, angle-angle graphs classified 6.7% of women with a history of breast cancer as having impaired scapulohumeral coordination across all scapular and clavicular rotations, and 6.7% of women with normal scapulohumeral coordination across all rotations. The percentage of women who were classified as having impaired coordination for 1 rotation was 30%, 2 rotations was 20%, 3 rotations was 23.3%, and 4 rotations was 10%. The proportion of women with a history of breast cancer that were classified with impaired scapulohumeral coordination for each specific scapular and clavicle rotation during un-weighted and weighted reaching can be found in Table 2.

2. RELATIVE MOTION ANALYSES

Relative motion graphs revealed that 93.3% of women with history of breast cancer demonstrated impaired scapulohumeral coordination for at least 1 scapular or clavicular rotation during un-weighted reaching. The percentage of women who demonstrated impaired coordination for 1, 2, 3, 4, or 5 rotations during un-weighted reaching was as follows: 6.7%, 20%, 26.7%, 23.3%, and 16.7%. For weighted reaching, all women demonstrated impaired scapulohumeral coordination for at least 1 rotation. The percentage of women who demonstrated impaired coordination for 1 rotation was 10%, 2 rotations was 6.7%, 3 rotations was 20%, 4 rotations was 26.7%, and 5 rotations was 33.3%. The proportion of women with a history of breast cancer that demonstrated impaired coordination for each specific scapular and clavicle rotation during un-weighted and weighted reaching can be found in Table 3.

Clinical Variables Associated with Impaired Scapulohumeral Coordination

For the sake of simplicity, the results reported in this section will only refer to the un-weighted reaching task with respect to the following scapular and clavicular rotations: UR, CE, and CP. It was decided to only report un-weighted reaching results due to the level of agreement for scapulohumeral coordination classification between the un-weighted and weighted tasks. There was substantial to perfect agreement for scapulohumeral coordination classification based on angle-angle graphs between un-weighted and weighted reaching tasks. Kappa values ranged from .68 to 1.0. For scapulohumeral coordination classification based on relative motion graphs, there was fair to moderate agreement between un-weighted and weighted reaching tasks evident by kappa values ranging from .32 to .53. Un-weighted reaching was chosen over weighted reaching due to clinical variable being able to better classify women with history of breast cancer as having impaired scapulohumeral coordination during un-weighted reaching. Results for the weighted reaching task can be found in Appendix C.

The rationale for selecting scapular UR and clavicular elevation and protraction rotations were as follows. Scapular UR is the predominant scapulothoracic motion that occurs during arm elevation. [32] While scapular IR and AT are important scapulothoracic motions these rotations are highly variable [32] and predominantly occur at arm elevation angles above 90° of arm elevation[49]. Clavicular elevation and protraction were chosen because women with history of breast cancer may experience impaired pectoral muscle flexibility due to trauma that may occur from surgery. [16,20,43] Additionally, radiation therapy has been shown to alter collagen synthesis[51-53], and cause soft tissue fibrosis affecting the flexibility of the pectoral muscles within the radiation field.[52-55], Impaired pectoral muscle flexibility is likely to directly or indirectly influence clavicular motion due to the anatomical orientation of the pectoral muscles. Additionally, clavicular elevation and protraction motions were not previously been measured by 3 out of 4 investigative groups who found that women with history of breast cancer demonstrate impaired scapulothoracic motion.[12-15, 21] Significant results for IR and AT can be found in Appendix D.

1. ANGLE-ANGLE GRAPH ANALYSES

Significant group (women classified with normal, more, or less scapular/clavicular motion) differences in continuous clinical variables were found for UR and CP during un-weighted reaching (Table 4).

Results of discriminant analysis for UR and CP can be found in Table 5. For un-weighted reaching, discriminant analysis revealed a significant association between groups and ER muscle strength normalized by body weight for UR ($p < .05$). Cross-validated classification showed that 43.3% of women were grouped correctly. For CP, discriminant analysis revealed a significant association between groups and resting pectoralis minor muscle length, elongated pectoralis minor muscle length, active shoulder ER ROM at 0° ABD, and active ER ROM at 90° ABD ($p < .05$). Cross-validated classification showed that 73.3% of women were grouped correctly.

2. RELATIVE MOTION ANALYSES

Results of the ANOVAs for continuous clinical variables that were significantly different between women with normal, more, or less relative scapular or clavicular motion during un-weighted reaching can be found in Table 6. Kruskal-Wallis test revealed significant differences in resting alignment variables for UR and CP (Table 7). However, these resting scapular alignment variables were not entered into the discriminant analyses due to causing fewer than two nonsingular group covariance matrices.

Discriminant analysis results for UR, CE, and CP can be found in Table 8. For scapular UR, there was significant association between groups and active ABD and % inter-limb volume difference during un-weighted reaching ($p < .05$). Cross-validated classification showed that 73.3% of women were grouped correctly. For CE, discriminant analysis revealed a significant association between groups and passive ABD and active ER at 0° ABD during un-weighted reaching ($p < .05$). Cross-validated classification showed that 71.4% of women were grouped correctly. Results of the discriminant analysis revealed that IR muscle strength was able to classify women as having normal, more, or less CP during un-weighted reaching ($p < .05$). Cross-validated classification showed that 67.9% of women were grouped correctly.

DISCUSSION

This study's findings demonstrate the value of using predication bands to investigate scapulohumeral coordination in women with a history of breast cancer. The results indicate that the majority of women with a history of breast cancer demonstrate impaired scapulohumeral coordination during overhead reaching. Data from the angle-angle graphs revealed that over 93% of women with a history of breast cancer demonstrated more or less motion for at least one scapular or clavicular rotation. This finding indicates that during overhead reaching tasks women with history of breast cancer have differences in the position/orientation of their scapula compared to women without history of breast cancer. Furthermore, over 93% of women with a history of breast cancer had at least 1 relative motion curves fall outside of the prediction bands derived from women without a history of breast cancer. This indicates that women with a history of breast cancer demonstrate more, or less, relative scapular motion of the scapula than women without a history of breast cancer.

ANGLE-ANGLE GRAPHS

We were able to identify clinical variables that classified women with history of breast cancer as having normal, more, or less scapular or clavicular motion. Impaired CP was associated with ER ROM and pectoralis minor length. This suggests that anterior shoulder girdle tissue flexibility is associated with impaired scapulohumeral coordination.

The pectoralis minor originates from the anterior surface of ribs 3 through 5 and inserts on the coracoid process. This orientation suggests that a smaller resting pectoralis minor muscle length could lead to a more forward shoulder posture, which in turn would be consistent with more CP during overhead reaching. Our finding of smaller normalized resting pectoralis minor muscle length in women who demonstrated more CP (pectoralis minor length = 61.3) when compared to women who demonstrated normal amounts of CP (pectoralis minor length = 63.5) supports this concept. It should be noted that this difference exceeds our standard error of measurement (1.4) for resting pectoralis minor length normalized by clavicle length but is less than the 90% minimal detectable change value (3.2) (Appendix A). A longer pectoralis minor length may allow for greater amounts of clavicular retraction (less CP) during overhead reaching. This is supported by the fact that the averaged normalized pectoralis minor muscle length for women who demonstrated less CP was 73.6.

Our failure to identify clinical variables associated with impaired CE may be due to the small percentage of women who demonstrated impairment in this rotation. During un-weighted reaching, we found that 63.3% and 60.0% of women with history of breast cancer demonstrated impaired UR and CP, respectively, compared to only 30% who demonstrated impaired CE coordination. It may also be due to the fact that we did not take measurements of all of the clinical variables that could possibly influence CE. For example, we did not measure serratus anterior or trapezius muscle strength. These muscles have been shown to play an important role in the production and control of scapular and clavicular motion.[56] This may also be the reason why ER muscle strength was the only variable associated with impaired UR, being able to only correctly classify 43.3% of subjects. Future studies should consider strength measures of these muscles.

RELATIVE MOTION GRAPHS

We were able to identify clinical variables associated with normal, more, or less relative motion during un-weighted reaching for UR, CE, and CP. ABD ROM was the only clinical variable, across multiple scapular and clavicular rotations, that was able to classify women with a history of breast cancer into normal, more, or less motion. Our findings revealed that women with less ABD ROM demonstrated more relative UR and CE motion.

Women with more relative CE had an average of 115.7° of passive ABD, while women with normal relative CE had an average of 170.6° and women with less relative CE had an average of 155.8° of passive ABD. Women with more relative upward rotation had an average of 108.7° of active ABD, while women with normal and less relative UR had an average of 158.2° and 151.8°, respectively. This finding is consistent with the finding that individuals with painful shoulders and limited glenohumeral ROM demonstrate more scapular UR during arm motion.[57-59] Overall these findings suggest that women with history of breast cancer demonstrate more scapulothoracic motion as a compensatory strategy in the presence of impaired glenohumeral motion.

Although the majority of women demonstrated impaired scapulohumeral coordination, which scapular or clavicular rotation was impaired (scapular UR, CE, and CE) and direction of impairment (i.e. more or less motion) varied between subjects. This is not surprising since women with a history of breast cancer may or may not experience a number of different impairments (soft tissue pain[6,7], decreased shoulder girdle muscle strength[6,7], decreased tissue flexibility[16], altered resting scapular alignment[17,18], and lymphedema[6,19]) that can influence scapulohumeral coordination.[20] Further research is needed to determine why some women with history of breast cancer experience these impairments and others do not even though the breast cancer treatment they received was the same.

LIMITATIONS

The method we used to derive our predication bands around the control group's mean curves could be viewed as a limitation. We chose to calculate predication bands as the 95% coverage probability using a minimal detectable change method. This method is commonly used in clinical practice to determine whether a true difference or a true change has occurred. Other methods such ±1 standard deviations, ±1.6449 standard deviations, and Bootstrap have been used to capture movement variability, with different methods resulting in different coverage probabilities.[22,60]

Another limitation of this study was that we did not assess all clinical factors that may influence scapulohumeral coordination. Although we assessed shoulder muscle strength, we did not assess other muscle performance measures such as endurance or muscle activity levels both of which may influence glenohumeral and scapulothoracic motion. While measures of anterior shoulder flexibility were included, posterior capsule tightness was not. Posterior capsule tightness has been found to influence scapulohumeral coordination.[58,61] Finally, our measure of pectoralis major flexibility was based on a computer simulation model and the validity of this measure has yet to be supported.

CONCLUSION

Although a large percentage of women with a history of breast cancer demonstrated impaired scapulohumeral coordination, a consistent impairment pattern was not identified. However, we were able to identify clinical variables associated with a number of different impaired scapulohumeral coordination patterns. We found that clinical measures of shoulder flexibility (pectoralis minor length) were associated with impaired CP coordination patterns. Another relevant finding was that shoulder ABD ROM was associated with impaired scapulohumeral coordination across multiple scapular and clavicular rotations.

It is our hope that these findings will lead to a better understanding of the relationships between shoulder flexibility (ROM and pectoralis minor) impairments and impaired scapulohumeral coordination. We also hope that this improved understanding will lead to the better intervention plans intended to restore optimal scapulohumeral coordination in order to maximize functional abilities and reduce risk of shoulder pain and dysfunction in women who have been treated for breast cancer.

FIGURES AND TABLES

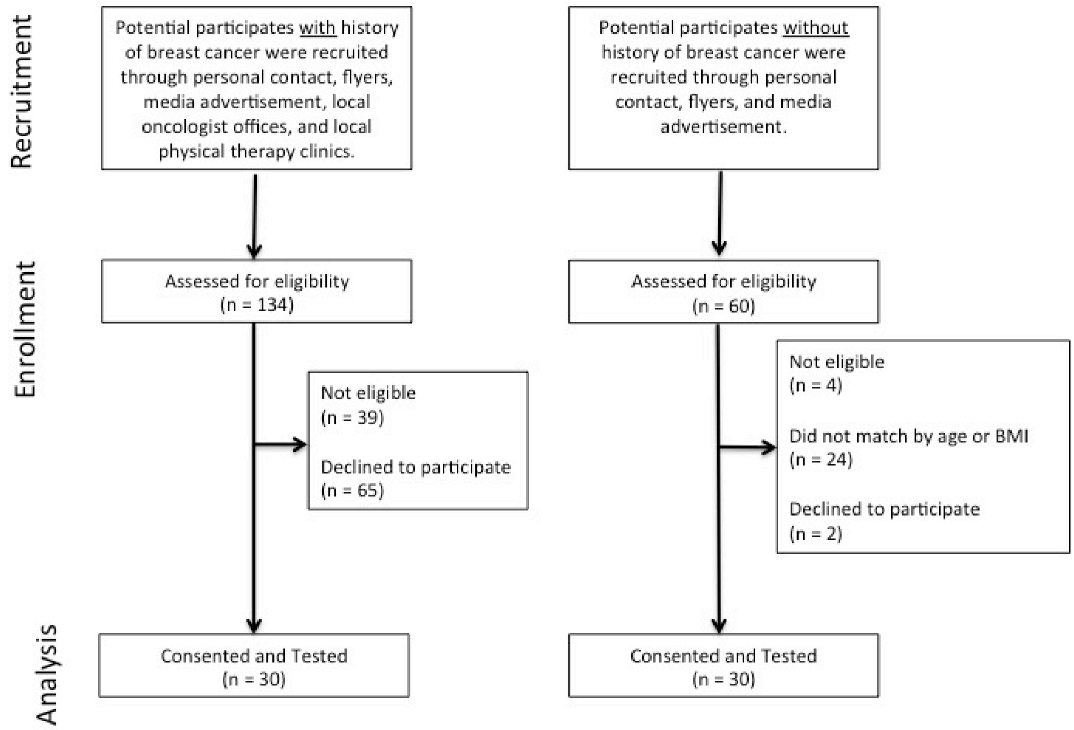

Figure 1: Flow diagram of subject recruitment and enrollment through different phases of the study

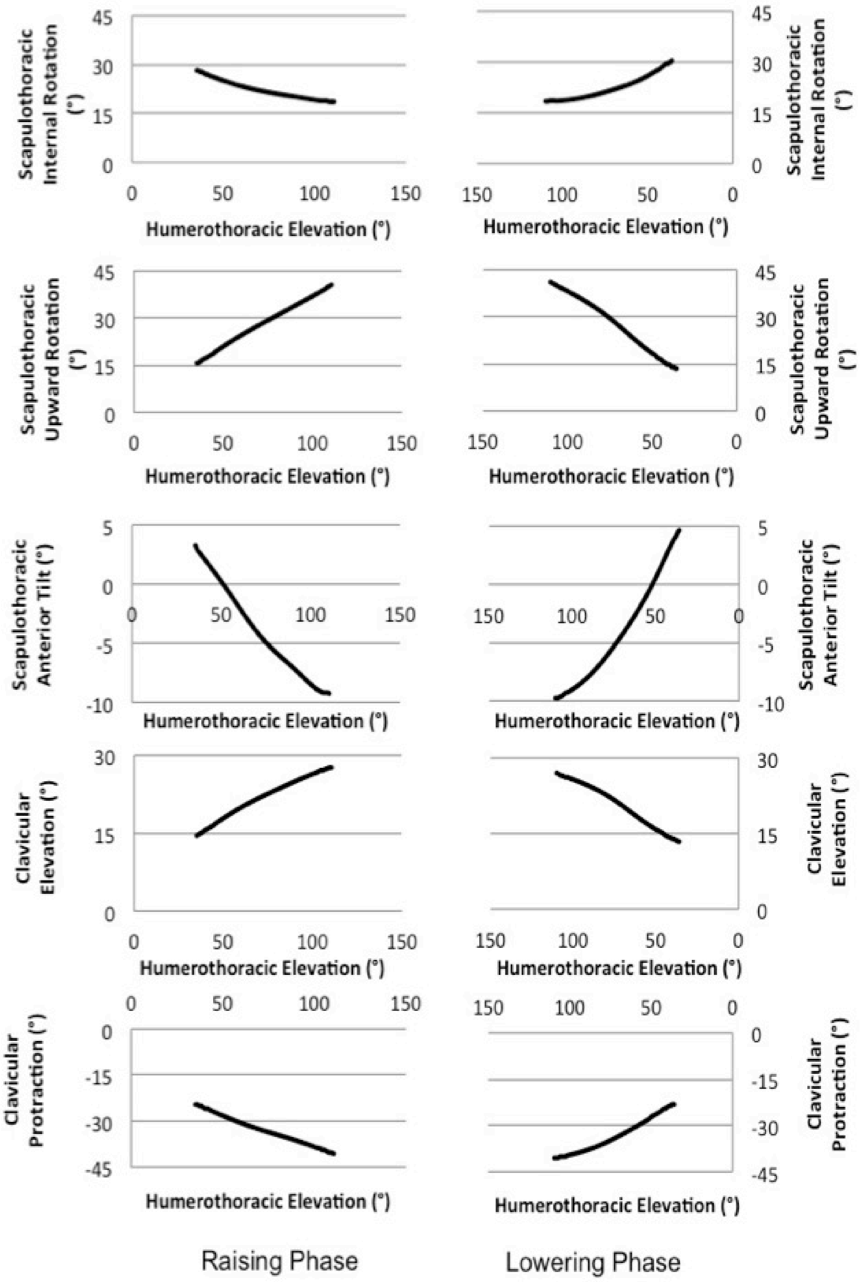

Figure 2: Angle-angle graphs: scapular and clavicular angular position on "Y" axis and humerothoracic elevation angular position on "X" axis

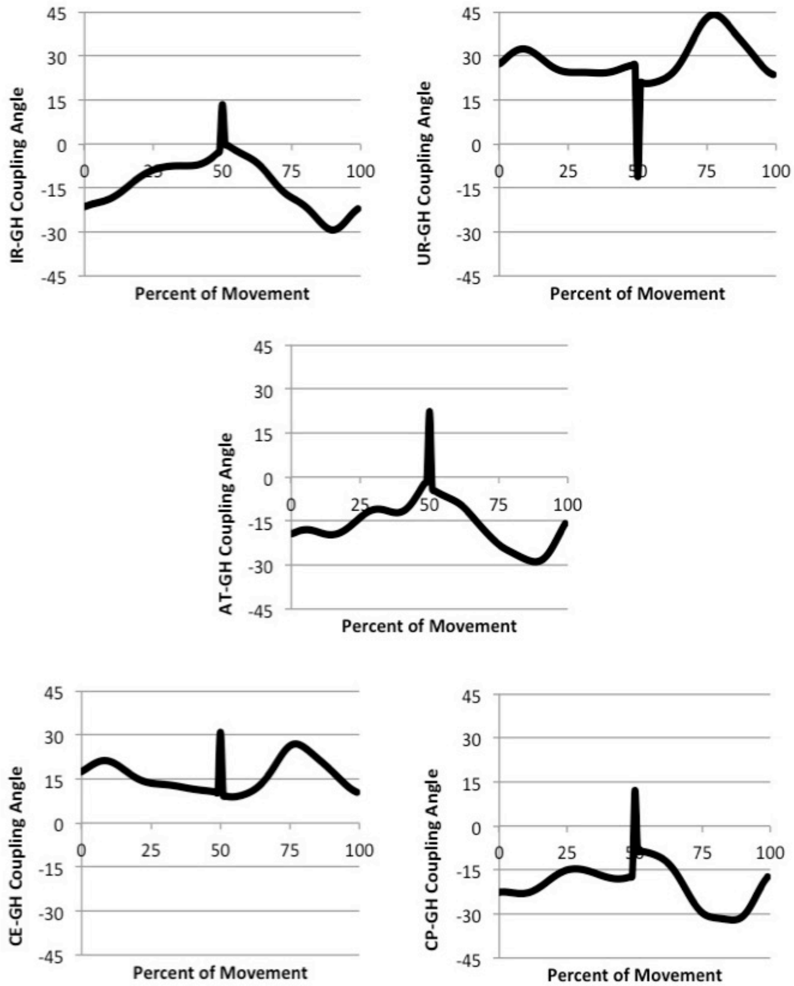

Figure 3: Relative motion graphs: scapular and clavicular coupling angle on “Y” axis and percent of movement on “X” axis. GH: glenohumeral elevation; IR: internal rotation; UR: upward rotation; AT: anterior tilt; CE: clavicular elevation; CP: clavicular protraction

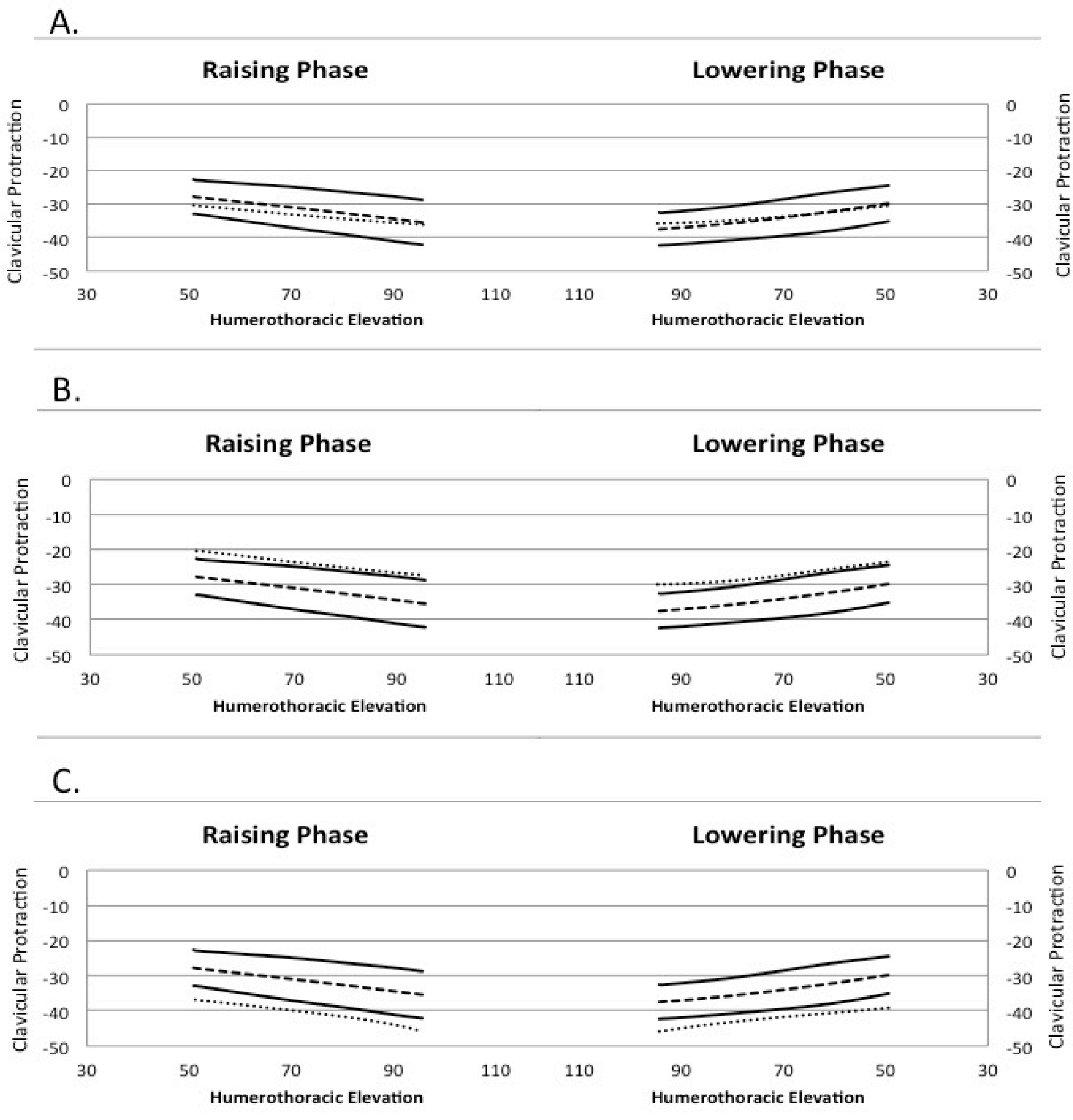

Figure 4: Angle-angle graphs. Mean of women without history of breast cancer (dashed black) & +/- minimal detectable change bands ($MDCB_{95}$) (solid black); A. Single subject classified as having normal motion (black dots); B. Single subject classified as having more motion (black dots); C. Single subject classified as having less motion (black dots)

Table 1: Descriptive statistics for all subjects (n = 60)

	BrCa (n = 30)	Controls (n =30)	p values
Age (years)			
Mean ± SD	53.8 ± 10.9	52.7 ± 10.8	ns
BMI (kg/m^2)			
Mean ± SD	28.3 ± 6.1	29.1 ± 6.0	ns
Race (n)			
Caucasian	18	16	ns
African-American	10	14	
Asian	2	0	
Penn Shoulder Score			
Pain Subscale	26.1 ± 5.8	29.7 ± .9	p < .05
Satisfaction Subscale	7.9 ± 2.9	9.2 ± 1.4	p < .05
Function Subscale	51.2 ± 11.7	57.5 ± 4.4	p < .05
Total Score	85.3 ± 19.5	96.4 ± 5.4	p < .05
Paffenbarger Physical Activity Questionnaire (kcal/wk)	1596 ± 943	1913 ± 1562	ns
Type of breast cancer treatment (n)			
Lumpectomy/radiation	20		
Mastectomy/reconstruction	10		
Type of lymph node surgery (n)			
SLNB	25		
ALND	5		
Side affected (n)			
Dominant side	17		
Non-dominant side	13		
Time since surgery (days)			
Mean ± SD	893 ± 325		
Chemotherapy (n)			
Yes	12		
No	18		
FPAX-B			
Mean ± SD	9.7 ± 11.1		
FACT-B + 4			
Mean ± SD	122.6 ± 22.0		
Educated on HEP (n)			
Yes	22		
No	8		
Attended physical therapy (n)			
Yes	17		
No	13		

BrCa: women with history of breast cancer treatment
ns: no significant difference between groups
FPAX-B: Fear of Physical Activity/Exercise Scale-Breast Cancer
FACT-B+4: Functional Assessment of Cancer therapy-Breast Cancer + 4

Table 2: Proportion of women with history of breast cancer who demonstrate normal, more, or less motion based on angle-angle graphs

		% Normal Motion (n)	% More Motion (n)	% Less Motion (n)
Un-weighted Reaching	Internal rotation	73.3 (22)	10.0 (3)	16.7 (5)
	Upward rotation	36.7 (11)	33.3 (10)	30.0 (9)
	Anterior tilt	63.3 (19)	20.0 (6)	16.7(5)
	Clavicular elevation	70.0 (21)	10.0 (3)	20.0 (6)
	Clavicular protraction	40.0 (12)	23.3 (7)	36.7 (11)
Weighted Reaching	Internal rotation	65.5 (19)	13.8 (4)	20.7 (6)
	Upward rotation	34.5 (10)	37.9 (11)	27.6 (8)
	Anterior tilt	51.7 (15)	34.5 (10)	13.8 (4)
	Clavicular elevation	69.0 (20)	10.3 (3)	20.7 (6)
	Clavicular protraction	58.6 (17)	20.7 (6)	20.7 (6)

Table 3: Proportion of women with history of breast cancer who demonstrate normal, more, or less motion based on relative motion graphs

		% Normal Motion (n)	% More Motion (n)	% Less Motion (n)	% More or Less Motion (n)
Un-weighted Reaching	Internal rotation	50.0 (15)	23.3 (7)	23.3 (7)	3.3 (1)
	Upward rotation	30.0 (9)	10.0 (3)	60.0 (18)	
	Anterior tilt	26.7 (8)	40.0 (12)	26.7 (8)	6.7 (2)
	Clavicular elevation	40.0 (12)	10.0 (3)	46.7 (14)	3.3 (1)
	Clavicular protraction	50.0 (15)	33.3 (10)	10.0 (3)	6.7 (2)
Weighted Reaching	Internal rotation	37.9 (11)	24.1 (7)	31.0 (9)	6.9 (2)
	Upward rotation	13.8 (4)	20.7(6)	55.2 (16)	10.3 (3)
	Anterior tilt	31.0 (9)	41.4 (12)	27.6 (8)	
	Clavicular elevation	31.0 (9)	27.6 (8)	41.4 (12)	
	Clavicular protraction	17.2 (5)	55.2 (16)	20.7 (6)	6.9 (2)

Table 4: Significant results of ANOVAs for angle-angle graph analysis during un-weighted reaching

Task	Rotation	Clinical Variables	Women with Less Motion Mean (SD)	Women with Normal Motion Mean (SD)	Women with More Motion Mean (SD)	df	F ratio	p value
Un-weighted Reaching	UR	Muscle Strength						
		ER (kg)	5.1 (1.7)	6.2 (1.6)	6.7 (1.4)	2, 29	2.550	p = .097
		FE Normalized	.10 (.02)	.14 (.05)	.14 (.04)	2, 29	3.776	p = .036
		ER Normalized	.06 (.02)	.09 (.03)	.10 (.02)	2, 29	7.602	p = .002
		IR Normalized	.08 (.03)	.12 (.04)	.12 (.03)	2, 29	4.745	p = .017
	CP	Active ROM						
		ER at 0° ABD	59.4 (13.8)	69.3 (11.8)	55.0 (13.7)	2, 29	3.095	p = .062
		ER at 90° ABD	73.8 (13.6)	87.9 (11.9)	80.7 (12.1)	2, 29	3.607	p = .041
		Pectoralis Minor Length						
		Resting#	96.5 (11.1)	90.2 (7.2)	85.5 (11.4)	2, 29	2.834	p = .076
		Resting*	73.6 (10.2)	63.5 (4.7)	61.3 (5.5)	2, 29	7.777	p = .002
		Elongated#	107.4 (12.6)	97.5 (8.2)	95.1 (12.1)	2, 29	3.485	p = .045
		Elongated*	82.0 (12.0)	68.6 (5.2)	68.2 (5.5)	2, 29	9.003	p = .001
		Elongated-Resting#	10.9 (4.6)	7.3 (2.5)	9.6 (2.3)	2, 29	3.417	p = .048
		Elongated-Resting*	8.4 (3.7)	5.1 (1.7)	6.9 (1.5)	2, 29	6.426	p = .018

- normalized by clavicle length; * - normalized by sternum length; FE – forward elevation; ER - external rotation; IR – internal rotation; ABD – abduction; UR – upward rotation; CP – clavicular protraction

Table 5: Results of the discriminant analysis for angle-angle graphs for un-weighted reaching

Task	**Rotation**	**Clinical Variables in Discriminant Analysis**	**Structure Matrix Correlations**		**Wilks' Lambda**	**Canonical Correlation (Effect Size)**	**p value**	**Cross-validation classification (% correctly grouped)**
Un-weighted Reaching	UR	ER muscle strength (N)	1.0		F1 = .640	F1 = .60 (.36)	p = .002	43.3
	CP		F1	F2				
		Resting PML (S)	.74	-.22	F1 = .323	F1 = .71 (.50)	p = .000	73.3
		Elongated PML (S)	.79	-.06	F2 = .659	F2 = .58 (.34)	p = .014	
		Active ER at 0° ABD ROM	-.08	.66				
		Active ER at 90° ABD ROM	.40	.45				

PML- pectoralis minor length; F1- function 1 of discriminant analysis; F2- function 2 of discriminant analysis;
ER -external rotation; ABD - abduction; ROM - range of motion; UR: upward rotation; CP: clavicular protraction
(N): normalized by body weight; (S): normalized by sternum length

Table 6: Significant Results of ANOVAs for Relative Motion Graphs Analysis during Un-weighted Reaching

Task	Rotation	Clinical Variable	Women with Less Motion Mean (SD)	Women with Normal Motion Mean (SD)	Women with More Motion Mean (SD)	df	F Ratio	p value
Un-weighted Reaching	UR	Active ROM						
		ABD (°)	151.8 (22.4)	158.2 (21.3)	108.7 (31.0)	2, 29	5.751	p = .098
		Passive ROM						
		ABD (°)	159.0 (22.4)	166.7 (22.3)	114.3 (52.0)	2, 28	4.759	p = .017
		ER at 0° ABD (°)	66.4 (11.8)	73.0 (9.5)	47.7 (21.0)	2, 29	4.817	p = .016
		ER at 90° ABD (°)	81.4 (12.0)	86.6 (11.9)	54.4 (48.6)	2, 29	3.936	p = .032
		Pectoralis Major Flexibility						
		Length (°)	234.4 (24.4)	245.3 (22.6)	198.8 (75.1)	2, 29	2.631	p = .090
		Lymphedema						
		ILVD (%)	-1.3 (4.4)	3.5 (5.7)	1.8 (4.4)	2, 29	3.007	p = .066
	CE	Active ROM						
		FE (°)	139.9 (16.1)	145.5 (13.6)	123.0 (17.4)	2, 28	2.972	p = .069
		ABD (°)	151.5 (22.6)	158.5 (22.1)	109.3 (31.2)	2, 28	5.709	p = .009
		ER at 0° ABD (°)	68.4 (9.7)	61.9 (13.2)	39.0 (13.2)	2, 28	8.233	p = .002
		IR(vertebral level)	T9 (4)	7.3 (1.1)	L2 (5)	2, 28	4.546	p = .020
		Passive ROM						
		ABD (°)	155.8 (28.0)	170.6 (8.7)	115.7 (51.7)	2, 27	5.505	p = .010
		ER at 0° ABD (°)	69.0 (12.1)	68.6 (11.3)	47.7 (21.0)	2, 28	3.409	p = .048
		ER at 90° ABD (°)	84.0 (10.8)	83.9 (12.0)	49.7 (47.0)	2, 28	5.598	p = .010
		IR (vertebral level)	T9 (4)	T7 (1)	L2 (5)	2, 28	4.159	p = .027
		Muscle Strength						
		ER (kg)	6.5 (1.7)	5.9 (1.0)	3.6 (1.3)	2, 28	5.136	p = .013
		Pectoralis Major Flexibility						
		Length (°)	237.4 (26.2)	242.0 (18.5)	190.7 (74.0)	2, 28	3.689	p = .039
	CP	Muscle Strength						
		IR (kg)	10.8 (2.2)	8.8 (1.9)	6.5 (2.6)	2, 27	5.972	p = .008
		Pain						
		Penn Shoulder Subscale	28.3 (2.9)	27.9 (7.9)	23.0 (5.9)	2, 27	2.603	p = 0.94

[h] - normalized by height; FE – forward elevation; ER - external rotation; IR – internal rotation; ABD – abduction; UR – upward rotation; CE – clavicular elevation; CP – clavicular protraction; ILVD: interlimb volume difference

Table 7: Significant results of the Kruskal-Wallis tests for relative motion graphs for un-weighted reaching (p < .10)*

Rotation	Resting Scapular Alignment Variable
Upward Rotation	Resting alignment final score
Clavicular Elevation	Clavicle was horizontal or slightly (10°) elevated

*: There was no significant differences in resting scapular alignment variables between groups classified based on angle-angle graphs

Table 8: Results of the discriminant analysis for relative motion graphs for un-weighted reaching

Task	Rotation	Clinical Variables in Discriminant Analysis	Structure Matrix Correlations		Wilks' Lambda	Canonical Correlation (Effect size)	p value	Cross-validation classification (% correctly grouped)
Un-weighted Reaching	UR*		F1	F2				73.3
		Active ABD ROM	1.0	.17	F1 = .562	F1 = .56 (.31)	p = .005	
		ILVD	-.33	.96	F2 = .814	F2 = .43 (.18)	p = .022	
	CE*		F1	F2				
		Passive ABD	.60	.80	F1 = .458	F1 = .63 (.40)	p = .001	71.4
		Active ER at 0° ABD ROM	1.0	-.08	F2 = .757	F2 = .49 (.24)	p = .009	
	CP	IR muscle strength	1.0		F1 = .677	F1 = .57 (.32)	p = .008	67.9

* - indicates that resting scapular alignment variable not entered into analysis due to causing fewer than two nonsingular group covariance matrices; F1- function 1 of discriminant analysis; F2 - function 2 of discriminant analysis; IR - internal rotation; ER- external rotation; ABD - abduction; ROM - range of motion; UR: upward rotation; CE: clavicular elevation; CP: clavicular protraction

APPENDIX A: Reliability and Measurement Error for Clinical Measures

Table: Summary of literature investigating the reliability and measurement error associated with clinical shoulder measures

Authors	Subjects	Clinical Measure	ICC	SEM	MDC (90%)
Mintken et al. 2009[38]	101 adults with shoulder pain who received physical therapy (mean age +/- SD of stable patients = 44.4 +/- 17.4 years; mean age +/- SD of improved patients = 39.1 +/- 18.8 years)	Numeric Pain Rating Scale	Test-retest = .74	1.07 points	2.5 points
Leggin et al. 1996[42]	17 adults (7 men with mean age = 31 +/- 5 years; 10 women with mean age 30 +/- 6 years) with no known shoulder dysfunction	Shoulder Strength	Intra-rater IR=.94- .97 ER=.89- .95 Elev. =.84-.96 Inter-rater IR=.90 ER=.94 Elevation=.79	Not reported	Not reported
Leggin et al. 2003[62]	40 adults (22 men with mean age = 42.4 +/- 11.7 years; 18 women with mean age = 54.8 +/- 17.1 years) receiving post-operative or non-operative rehabilitation for a variety of shoulder conditions	Shoulder Strength	Interrater IR=.91 ER=.89 Elevation=.93	IR=2.2kg ER=1.4kg Elevation=1.9kg	IR=3.1kg ER=3.3kg Elevation=2.7kg
Leggin et al. 2003[62]	40 adults (22 men with mean age +/- SD = 42.4 +/- 11.7 years; 18 women with mean age +/- SD = 54.8 +/- 17.1 years) receiving post-operative or non-operative rehabilitation for a variety of shoulder conditions	Shoulder ROM	Interrater FE=.89 ER at 0°=.89 ER at 90°=.88 IR=.86	FE=12.3° ER at 0°=10.3° ER at 90°=17.9° IR=2 levels	FE=17.4° ER at 0°=14.6° ER at 90°=25.3° IR=3 levels

ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC = minimal detectable change; ROM = range of motion; FE = forward elevation; ER = external rotation; IR = internal rotation; V = volume; h = height; C = circumference

Table (continued): Summary of literature investigating the reliability and measurement error associated with clinical shoulder measures

Authors	**Subjects**	**Clinical Measure**	**ICC**	**SEM**	**MDC (90%)**
Harrington et al. 2011[63]	Pilot data on breast cancer survivors (number of subjects was not reported)	Shoulder AROM/PROM (supine flexion, ER at 0° abduction, ER at 90° abduction, IR at 90° abduction, prone extension	Intrarater AROM = .84-1.0 PROM = .97-1.0	Not reported	Not reported
Ebaugh and Oravitz, 2008[64]	8 healthy subjects (4 men; mean age = 24.1 years)	Pectoralis Minor Length (resting and elongated)	Intra-rater = .98-.99 Inter-rater = .86-.95	Not reported	Intra-rater .5 – .8 cm Inter-rater 1.4 – 2.2 cm
Sander et al. 2002[65]	50 women with primary or secondary lymphedema (mean age +/- SD = 56 +/- 13.3 years)	Limb volume V = $\Sigma\ (hC_i^2/4\pi)$ h = 3, 6, or 9cm	Intra-rater = .99 Inter-rater = .99	h= 3cm: 120mL h= 6cm: 124 mL h= 9cm: 130mL	Not reported
Deltombe et al. 2007[66]	30 women with unilateral breast cancer related lymphedema (mean age +/- SD = 63 +/- 9 years)	Limb volume V = $\Sigma\ (hC_i^2/4\pi)$ h = 5cm	Intra-rater = .99 Inter-rater = .99	Not reported	Not reported
Czerniec et al. 2010[67]	33 women with breast cancer related lymphedema (mean age +/- SD = 58.6 +/-10 years); 18 women without history of either lymphedema or breast cancer (mean age +/- SD = 52.2 +/-7 years)	Limb volume V= $\Sigma\ h\ (C_i^2+C_i^2C_{i-1}^2+C_{i-1}^2)$ $/12\pi$ h = 10 cm	Lymphedema group Inter-rater = .98 Control group Inter-rater = .98	93mL	Not reported

ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC = minimal detectable change; ROM = range of motion; FE = forward elevation; ER = external rotation; IR = internal rotation; V = volume; h = height; C = circumference

Table: Intraclass correlation coefficient ($ICC_{(3, 2)}$), standard error of measurement (SEM) and minimal detectable change ($MDC_{90\%}$) values for pectoralis minor length and pectoralis major length calculated from 10 of the women with history of breast cancer treatment

	ICC (95%CI)	SEM	MDC90%
Resting PML normalized by clavicle length	.98 (.99, 1.0)	1.4	3.2
Resting PML normalized by sternum length	.99 (.94, 1.0)	.8	1.9
Resting PML normalized by height	.98 (.90, .99)	.1	.3
Elongated PML normalized by clavicle length	.97 (.86, .99)	1.8	4.1
Elongated PML normalized by sternum length	.98 (.91, 1.0)	1.3	3.0
Elongated PML normalized by height	.95 (.79, .99)	.2	.4
Elongated – Resting PML normalized by clavicle length	.82 (.27, .96)	1.2	2.7
Elongated – Resting PML normalized by sternum length	.80 (.20, .95)	.9	2.2
Elongated – Resting PML normalized by sternum length	.79 (.16, .95)	.1	.3
Pectoralis Major Length (°)	.99 (.99, 1.0)	4.8	11.1

Appendix B: Coupling Angles and Minimal Detectable Change Calculations

Coupling angles were derived from the following formula:

$$\text{Coupling angle} = a\ tan\ [\frac{Yi+1 \quad - Y_i}{X_{i+1} - X_i}]$$

, where Y and X are data points obtained from angle-angle graphs in which motion of the distal segment is plotted on the x-axis and motion of the proximal segment is plotted on the y-axis.[24]

Minimal detectable change values were calculated from the following formula:

$$MDC\% = z\ score * SEM * \sqrt{2}$$

, where the z score for 95% is 1.96. SEM is standard error of measurement calculated from the following formula:

$$SEM = SD\sqrt{1 - ICC}$$

, where SD is the standard deviation across subjects. ICC is the intraclass correlation coefficient calculated from the following formula:

$$\text{ICC (2, 3)} = \frac{MS_{BS} - MS_E}{MS_{BS} - \frac{k\,(MS_{BR} - MS_E)}{n}}$$

,where MS_{BS} is the between-subjects mean square; MSE is the error mean square; MSBR is the between-raters mean square; k is number of raters; and n is number of subjects. ICC coefficients were calculated from a pilot study in our lab that investigated the between day reliability of our kinematic measurements.

Appendix C: Weighted Reaching Analysis

Table: Significant results of ANOVAs for angle-angle graph analysis during weighted reaching

Task	Rotation	Clinical Variables	Women with Less Motion Mean (SD)	Women with Normal Motion Mean (SD)	Women with More Motion Mean (SD)	df	F ratio	p value
Weighted Reaching	IR	Pectoralis Minor Length						
		Resting#	99.9 (11.1)	88.2 (8.4)	91.8 (12.8)	2, 28	3.414	p = .048
		Elongated#	110.6 (12.5)	97.3 (9.8)	99.1 (15.2)	2, 28	3.323	p = .052
		Lymphedema				2, 28	2.662	p = .089
		ILVD (%)	-.7 (4.5)	-.2 (4.3)	5.6 (7.9)			
	UR	Muscle Strength						
		FE Normalized	.10 (.02)	.14 (.05)	.14 (.04)	2, 28	2.804	p = .079
		ER Normalized	.06 (.02)	.09 (.03)	.10(.02)	2, 28	6.627	p = .005
		IR Normalized	.08 (.03)	.12 (.04)	.12 (.03)	2, 28	3.417	p = .048
	AT	Active ROM						
		IR (vertebral level)	T6 (4)	T9 (2)	T10 (4)	2, 28	2.632	p = .091
		Passive ROM						
		IR (vertebral level)	T6 (4)	T9 (2)	T10 (4)	2, 28	2.625	p = .092
	CP	Active ROM						
		IR (vertebral level)	T11 (3)	T7 (3)	T10 (4)	2, 28	3.243	p = .055
		Passive ROM						
		IR (vertebral level)	T11 (3)	T7 (3)	T10 (4)	2, 28	3.148	p = .060
		ER at 90° ABD (°)	65.9 (33.0)	85.4 (11.6)	82.8 (14.6)	2, 28	2.575	p = .095
		Pectoralis Minor Length						
		Elongated-Resting#	11.5 (5.6)	8.0 (2.6)	10.4 (3.4)	2, 28	2.545	p = .098
		Elongated-Resting*	8.8 (4.5)	5.8 (2.0)	7.6 (2.6)	2, 28	2.991	p = .068

- normalized by clavicle length; * - normalized by sternum length; FE – forward elevation; ER - external rotation; IR – internal rotation; ABD – abduction; ILVD – interlimb volume difference; UR – upward rotation; AT – anterior tilt; CP – clavicular protraction

Table: Significant results of the Kruskal-Wallis tests for angle-angle graphs for weighted reaching ($p < .10$)*

Rotation	**Resting Scapular Alignment Variable**
Clavicular Protraction	Scapular lies flat against thorax

Table: Results of the discriminant analysis for angle-angle graphs for weighted reaching

Task	**Rotation**	**Clinical Variables in Discriminant Analysis**	**Structure Matrix Correlations**		**Wilks' Lambda**	**Canonical Correlation**	**p value**	**Cross-validation classification (% correctly grouped)**
Weighted Reaching	IR		F1	F2				
		Resting PML (C)	.90	.44	F1 = .655	F1 = .47	p = .029	69.0
		ILVD	-.35	.94	F2 = .837	F2 = .40	p = .033	
	UR	ER muscle strength (N)	1.0		F1 = .662	F1 = .58	p = .005	51.7
	AT	Active IR ROM	1.0		F1 = .832	F1 = .41	p = .091	63.3
	CP		F1	F2				
		Active IR ROM	.37	-.86	F1 = .352	F1 = .80	p = .000	55.2
		RSA	.35	.67	F2 = .992	F2 = .09	p = .097	
		Resting-Elongated PML (S)	.36	-.04				

PML - pectoralis minor length; F1 - function 1 of discriminant analysis; F2 - function 2 of discriminant analysis; IR - internal rotation;
ER -external rotation; ABD - abduction; ROM - range of motion; ILVD - inter-limb volume difference; UR - upward rotation; AT- anterior tilt;
CP - clavicular protraction
(N) - normalized by body weight; (C) - normalized by clavicle length; (S) - normalized by sternum length;
RSA - resting scapular alignment variable "scapula lies flat against thorax" resting scapular alignment

Table: Significant results of ANOVAs for relative motion graphs analysis during weighted reaching

Task	Rotation	Clinical Variable	Women with Less Motion Mean (SD)	Women with Normal Motion Mean (SD)	Women with More Motion Mean (SD)	df	F Ratio	p value
Weighted Reaching	IR	Active ROM						
		FE	144.0 (15.5)	144 (12.0)	131.4 (14.3)	2, 26	2.651	p = .091
		ABD	159.0 (23.7)	155.1 (15.8)	129.6 (32.9)	2, 26	3.720	p = .039
		Passive ROM						
		ABD	158.3 (28.8)	171.6 (6.8)	135.3 (38.2)	2, 25	4.319	p = .026
		Muscle Strength						
		FE_Normalized	.14 (.04)	.13 (.03)	.10 (.03)	2, 26	2.951	p = .071
	UR	Active ROM						
		ABD	154.0 (20.4)	168.5 (11.8)	129.3 (35.0)	2, 25	3.924	p = .034
		ER at 0° ABD	64.8 (13.1)	68.0 (15.0)	50.2 (14.9)	2, 25	2.702	p = .088
		IR (vertebral level)	T8 (3)	T7 (1)	T11 (5)	2, 25	2.783	p = .083
		Passive ROM						
		ABD	162.0 (18.8)	177.0 (4.8)	132.2 (44.1)	2, 24	4.241	p = .028
		ER at 0° ABD	69.1 (11.5)	72.8 (12.0)	53.2 (14.7)	2, 25	3.765	p = .038
		ER at 90° ABD	84.0 (12.5)	85.9 (7.6)	65.1 (34.7)			
		IR (vertebral level	T8 (3)	T7 (1)	T11 (4)	2, 25	2.646	p = .092
		Muscle Strength						
		FE_Normalized	.13 (.04)	.14 (.01)	.10 (.02)	2, 25	2.813	p = .081
		Lymphedema						
		ILVD (%)	-1.7	6.2 (3.4)	1.7 (6.4)	2, 25	4.456	p = .023
	CP	Muscle Strength						
		ER_Normalized	.06 (.02)	.09 (.01)	.09 (.02)	2, 26	6.239	p = .007
		IR_Normalized	.09 (.02)	.11 (.04)	.11 (.04)	2, 26	3.097	p = .064

FE – forward elevation; ER - external rotation; IR – internal rotation; ABD – abduction; UR – upward rotation; CP – clavicular protraction; ILVD: interlimb volume difference

Table: Significant results of the Kruskal-Wallis tests for relative motion graphs for weighted reaching ($p < .10$)*

Rotation	Resting Scapular Alignment Variable
Upward Rotation	Clavicle was horizontal or slightly (10°) elevated
Anterior Tilt	Clavicle was horizontal or slightly (10°) elevated
Clavicular Protraction	Clavicle was horizontal or slightly (10°) elevated

Table: Results of the discriminant analysis for relative motion graphs for weighted reaching

Task	Rotation	Clinical Variables in Discriminant Analysis	Structure Matrix Correlations		Wilks' Lambda	Canonical Correlation	p value	Cross-validation classification (% correctly grouped)
Weighted Reaching	IR	Active ABD ROM#	1.0		F1 = .763	F1 = .49	p = .039	44.4
	UR		F1	F2				
		Passive ABD ROM	-.48	.35	F1 = .285	F1 = .77	p = .000	76.0
		ILVD	.15	.92	F2 = .695	F2 = .55	p = .022	
		RSA	.53	-.11				
	CP	ER muscle strength (N)	1.0		F1 = .658	F1 = .59	p = .007	66.7

F1- function 1 of discriminant analysis; F2 - function 2 of discriminant analysis; IR - internal rotation; ABD - abduction; ROM - range of motion;
ILVD - inter-limb volume difference; (N) - normalized by body weight (kg);
- only clinical variable entered due fewer than two nonsingular group covariance matrices when other variables entered into discriminant analysis;
RSA- resting scapular alignment variable "the clavicle was either horizontal or elevated by 6°-10° at the acromial end"

Appendix D: Internal Rotation and Anterior Tilt Analysis for Un-weighted Reaching

Table: Significant results of ANOVAs for angle-angle graph analysis during un-weighted reaching

Task	Rotation	Clinical Variables	Women with Less Motion Mean (SD)	Women with Normal Motion Mean (SD)	Women with More Motion Mean (SD)	df	F ratio	p value
Un-weighted Reaching	IR	Pectoralis Minor Length						
		Resting#	100.3 (8.6)	88.9 (9.5)	94.9 (13.4)	2, 29	2.984	p = .067
	AT	Active ROM						
		ABD	165.8 (19.8)	150.9 (21.0)	130.8 (36.9)	2, 29	2.943	p = .070
		ER at 0° ABD	70.6 (8.4)	64.7 (12.0)	50.3 (16.8)	2, 29	3.873	p = .033
		IR(vertebral level)	T7 (4)	T9 (3)	T12 (4)	2, 29	2.695	p = .086
		Passive ROM						
		ABD	174.6 (7.8)	159.5 (21.9)	133.7 (36.9)	2, 29	3.399	p = .049
		ER at 0° ABD	76.2 (8.2)	67.6 (11.3)	55.2 (17.7)	2, 29	3.867	p = .033
		ER at 90° ABD	91.2 (4.4)	82.6 (11.6)	64.0 (34.3)	2, 29	3.766	p = .036
		IR (vertebral level)	T7 (4)	T9 (3)	T12 (4)	2, 29	2.547	p = .097

- normalized by clavicle length; ER - external rotation; IR – internal rotation; ABD – abduction; AT – anterior tilt

Table: Results of the discriminant analysis for angle-angle graphs for un-weighted reaching

Task	Rotation	Clinical Variables in Discriminant Analysis	Structure Matrix Correlations	Wilks' Lambda	Canonical Correlation	p value	Cross-validation classification (% correctly grouped)
Un-weighted Reaching	IR	Resting PML (C)	1.0	F1 = .819	F1 = .43	p = .067	73.3
	AT	Passive ER at 0° ABD ROM	1.0	F1 = .761	F1 = .49	p = .029	63.3

PML - pectoralis minor length; F1 - function 1 of discriminant analysis; ER - external rotation; ABD - abduction; ROM - range of motion; AT - anterior tilt; (C) - normalized by clavicle length

Table: Significant results of ANOVAs for relative motion graphs analysis during un-weighted reaching

Task	Rotation	Clinical Variable	Women with Less Motion Mean (SD)	Women with Normal Motion Mean (SD)	Women with More Motion Mean (SD)	df	F Ratio	p value
Un-weighted Reaching	IR	Active ROM						
		FE (°)	152.3 (4.0)	142.4 (14.6)	123.3 (13.3)	2, 28	9.946	p = .001
		ABD (°)	170.9 (4.3)	155.5 (18.2)	117.4 (25.4)	2, 28	17.155	p = .000
		ER at 0° ABD (°)	72.1 (7.9)	62.4 (14.9)	55.1 (13.5)	2, 28	3.007	p = .067
		ER at 90° ABD (°)	92.7 (8.8)	80.5 (12.0)	70.3 (14.3)	2, 28	6.449	p = .005
		IR (vertebral level)	T7 (3)	T8 (3)	L1 (4)	2, 28	5.685	p = . 009
		Passive ROM						
		FE (°)	166.3 (6.1)	154.8 (11.0)	137.0 (15.9)	2, 28	12.016	p = .000
		ABD (°)	174.4 (5.2)	166.0 (19.6)	118.7 (28.7)	2, 27	16.751	p = .000
		ER at 0° ABD (°)	73.0 (7.0)	69.3 (13.4)	54.7 (14.5)	2, 28	3.975	p = .031
		ER at 90° ABD (°)	90.5 (2.9)	81.6 (14.4)	65.3 (29.7)	2, 28	3.787	p = .036
		IR (vertebral level)	T7 (3)	T8 (3)	T12 (4)	2, 28	5.481	p = .01
		Muscle Strength						
		FE (Normalized)	.15 (.03)	.13 (.03)	.08 (.01)	2, 28	9.031	p = .001
		IR (Normalized)	.14 (.03)	.11 (.03)	.08 (.03)	2, 28	5.597	p = .010
		Pectoralis Minor Length						
		Resting[h]	9.1 (1)	8.4 (.9)	9.7 (1.1)	2, 28	4.050	p = .029
		Elongated[h]	10.1 (1.1)	9.3 (.9)	10.7 (1.6)	2, 28	3.628	p = .041
		Pectoralis Major Flexibility						
		Length (°)	256.8 (8.5)	236.5 (23.1)	202.3 (42.2)	2, 28	7.759	p = .002
		Pain						
		Penn Shoulder Subscale	29.4 (1.1)	27.8 (4.8)	19.0 (5.5)	2, 28	12.461	p = .000
		Pain with motion	0.0	.8 (1.9)	3.4 (2.4)	2, 28	7.408	p = .003
	AT	Muscle Strength						
		ER (Normalized)	.07 (0.03)	.08 (.02)	.10 (.03)	2, 27	3.029	p = .066

[h] - normalized by height; FE – forward elevation; ER - external rotation; IR – internal rotation; ABD – abduction; AT – anterior tilt

Table: Significant results of the Kruskal-Wallis tests for relative motion graphs for un-weighted reaching ($p < .10$)*

Rotation	Resting Scapular Alignment Variable
Anterior Tilt	Scapula lies flat against the thorax

*: There was no significant differences in resting scapular alignment variables between groups classified based on angle-angle graphs

Table: Results of the discriminant analysis for relative motion graphs for un-weighted reaching

Task	Rotation	Clinical Variables in Discriminant Analysis	Structure Matrix Correlations		Wilks' Lambda	Canonical Correlation	p value	Cross-validation classification (% correctly grouped)
			F1	F2				
Un-weighted Reaching	IR	Passive ABD ROM	.64	.24	F1 = .332	F1 = .87	p = .000	75.0
		Penn Shoulder Score Pain Subscale	.54	.21	F2 = .805	F2 = .73	p = .002	
		Pectoralis Major Length	.39	.35				
		Resting PML (H)	-.29	.25				
		IR muscle strength (N)	.34	.40				
	AT*	ER muscle strength (N)	1.0		F1 = .805	F1 = .44	p = .066	46.4

* - indicates that resting scapular alignment variable not entered into analysis due to causing fewer than two nonsingular group covariance matrices; F1 - function 1 of discriminant analysis; F2 - function 2 of discriminant analysis; IR - internal rotation; ER - external rotation; ABD - abduction; ROM- range of motion; (N): normalized by body weight (kg); AT: anterior tilt

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CHAPTER 4: SUMMARY CHAPTER

Breast cancer is the most common type of cancer that affects women.[1] Due to advancements in breast cancer treatment survival rates have improved.[1] However, many women experience shoulder and arm problems after treatment that negatively impacts health related quality of life (HRQoL).[2,3] Impaired shoulder motion is a well-documented problem that some women continue to experience years after treatment.[4]

The rationale for impaired shoulder motion amongst breast cancer survivors is that these women frequently experience impairments such as soft tissue pain[4,5], decreased shoulder girdle muscle strength[4,5], decreased tissue flexibility[6], altered resting scapular alignment[7,8], and lymphedema[4,9]. However, the association between these impairments and impaired motion and coordination of the shoulder complex has yet to be supported. Furthermore, the current understanding of impaired shoulder motion is limited to traditional measures of shoulder motion such as the amount of humeral motion with respect to the trunk with little regard to the complex interaction between glenohumeral (GH) and scapulothoracic (ST) motion (scapulohumeral coordination).

The objective of this dissertation was to determine the effect that breast cancer treatment (lumpectomy/radiation and mastectomy/reconstruction) has on shoulder girdle motion, shoulder girdle coordination, and select musculoskeletal structures of the shoulder. The rationale for this research is that a better understanding of motion and coordination impairments, and the clinical factors associated with these problems may lead to improved evidence based examination, intervention, and prevention procedures. This in turn may lead to a reduction in the prevalence of shoulder pain and dysfunction, which could then lead to improved HRQoL amongst breast cancer survivors.

The following two specific aims were addressed in this dissertation: 1) determine the effect that breast cancer treatments (lumpectomy and radiation, and mastectomy with breast reconstruction) have on motion and coordination of the shoulder complex; 2) identify clinical factors associated with impaired coordination of the shoulder complex in women with a history of breast cancer treatment. Chapter 2 (Specific Aim 1) focused on determining whether women with history of breast cancer demonstrated group differences in shoulder girdle motion (glenohumeral and scapulothoracic) compared to women without a history of breast cancer during functional reaching tasks. Chapter 3 (Specific Aim 2) focused on identifying the proportion of women with a history of breast cancer who demonstrated impaired shoulder girdle coordination. In order to accomplish this, a statistical approach that is novel to the shoulder complex was employed. The statistical approach involved deriving continuous motion angle-angle and relative motion graphs with prediction bands. Additionally, a discriminant analysis procedure was used to identify clinical factors that were able to classify women with history of breast cancer as having impaired shoulder girdle coordination.

CONCLUSIONS

The results of the Specific Aim 1 study, reported in Chapter 2, failed to support our hypothesis that: 1) women with a history of breast cancer will demonstrate impairments in GH and ST motion during functional reaching tasks compared to women without a history of breast cancer treatment, 2) women with a history of lumpectomy and radiation will demonstrate greater impairments in motion during functional reaching tasks when compared to women treated with mastectomy and reconstruction, and 3) women with a history of mastectomy and reconstruction will demonstrate impairments in motion during functional reaching tasks compared to women without a history of breast cancer treatment.

Women with a history of breast cancer had an average (SD) of 141.1° (16.1°) of active forward elevation range of motion (ROM), 150.0° (26.1°) of active abduction (ABD) ROM, and 81.2° (13.9°) of active external rotation (ER) at 90° ABD ROM. Although the amount of forward elevation, ABD, and ER were significantly different than women without history of breast cancer [women without history of breast cancer had an average (SD) of 148.9° (7.7°) of forward elevation, 164.6° (9.5°) of ABD, and 96.6° (10.5°) of ER at 90° ABD], the minimum amount of forward elevation ROM amongst women with history of breast cancer was 115°, which is significantly greater than the 85° of humerothoracic elevation at which we derived our ST and GH ROM data.

The average maximum humerothoracic elevation that women without a history of breast cancer achieved during overhead reaching in our study was 117.0° (range 99.8° to 135.2°). Women with a history of breast cancer across breast treatments achieved similar amounts of humerothoracic elevation (an average of 119.6° of humerothoracic elevation and range of 91.7° to 140.0°). The average maximum humerothoracic elevation that was achieved during hair combing in women without and with a history of breast cancer was 113.2° (range 89.7° to 141.8°) and 115.0° (range 89.6° to 133.6°), respectively. This is consistent with Rundquist et al 2009[10], who reported women achieved an average of 119° during hair combing.

Both groups of women (with and without a history of breast cancer) demonstrated similar patterns of ST and GH motion. Across subjects, the scapula generally upwardly rotated and posteriorly tilted during overhead reaching and hair combing, while the clavicle elevated and retracted. Minimal amounts of ST internal/external rotation occurred during all three functional tasks. The predominant ST and GH motions that occurred during all functional tasks were ST upward rotation and GH elevation, respectively. Across all three tasks, women on average demonstrated 17.4° to 19.2° of ST upward rotation and 57.0° to 60.0° of GH elevation.

Failure to find group differences in motion may be because of the fact that women in our study demonstrated relatively low levels of shoulder pain and disability. Only 46.7% of women with history of breast cancer reported experiencing shoulder pain with the average pain ± SD level on the Penn Shoulder Score-Pain Subscale being 26.1 ± 5.8, where 30 indicates no pain. The average Penn Shoulder Score-Function Subscale score for women with a history of breast cancer was 51.2 ± 11.7 while women without a history of breast cancer average ± SD score was 57.5 ± 4.4, where 60 indicates no functional deficits related to the upper extremity. Review of the Penn Shoulder Score responses revealed that items which were similar to the tasks women performed in our study were performed “without difficulty” for the majority of our subjects with a history of breast cancer. Only 6 out of 30 women with a history of breast cancer reported at least “some difficulty” related to combing hair (item 5). Seven out of 30 women with history of breast cancer reported at least “some difficulty” with reaching a shelf above head (item 14), and 8 out of 30 reported at least “some difficulty” with placing a soup can (1-2 lb.) on a shelf overhead (item 15). All of the women with a history of breast that reported at least “some difficulty” were treated with lumpectomy and radiation, and not a single woman treated with mastectomy and reconstruction reported difficulty with combing hair, reaching a shelf, or placing a soup can overhead.

Of interest is the finding that a significant correlation existed between women with a history of breast cancer's Penn Shoulder Score-Pain Subscale scores and glenohumeral external rotation during un-weighted reaching ($r = .57$, $p < .05$) and weight reaching ($r = .48$, $p < .05$), scapulothoracic upward rotation ROM during un-weighted reaching ($r = .36$, $p < .05$), and clavicular retraction ROM during hair combing ($r = .37$, $p < .05$). Penn Shoulder Score-Function Subscale scores were significantly correlated with glenohumeral external rotation ROM during un-weighted ($r = .57$, $p < .05$) and weighted reaching ($r = .53$, $p < .05$). For all subjects (women with and without a history of breast cancer), there was a significant correlation between Penn Shoulder Score-Pain Subscale scores and scapulothoracic upward rotation ROM during un-weighted reaching ($r = .31$, $p = .02$), hair combing ($r = .30$ $p = .02$), and clavicular retraction ROM during hair combing ($r = .29$, $p = .02$). Penn Shoulder Score-Function Subscale scores were significantly correlated with glenohumeral external rotation during un-weighted ($r = .30$, $p = .02$) and weighted reaching ($r = .28$, $p = .03$). This suggests that findings from the Penn Shoulder Score may be useful for helping clinicians determine which shoulder complex motions should be a focus of their examination. The relationship between shoulder pain and disability as measured by a functional outcome score and motion of the shoulder complex in women with a history of breast cancer warrants further investigation.

Relatively low shoulder pain and disability scores were reported by women in our study. This may be due to the fact that 73.3% reported being educated on a home exercise program, which women reported being approximately 65.9% adherent to, and 56.7%

reported attending physical therapy for an average of 7.5 visits. Home exercise program education and performance may also have contributed to the lack of motion differences between these groups. This point needs to be systematically examined in prospective studies.

Although we did not find group differences between women with and without a history of breast cancer in the amount of ST and GH motion across functional tasks, findings from the study conducted in Chapter 3 indicate that the majority women with a history of breast cancer demonstrate impaired scapulohumeral coordination. In Chapter 3 we used a statistical approach and continuous kinematic data to derive angle-angle and relative motion graphs along with predication bands. Individually comparing the movement patterns of a woman with a history of breast cancer to a population of women without a history of breast cancer allowed for the identification of the proportion of women with impaired scapulohumeral coordination during overhead reaching tasks. Analysis of angle-angle and relative motion graphs revealed that over 93% of women with history of breast cancer demonstrated impaired scapulohumeral coordination during un-weighted and weighted reaching.

Although differences in the absolute position of the scapula (angle-angle graphs) and relative motion of the scapula or clavicle compared to motion of the humerus (relative motion graphs) were found between women with and without a history of breast cancer, which scapular or clavicular rotation was impaired [i.e. clavicular protraction (CP), scapular upward rotation (UR), etc.) and the impairment direction (i.e. more or less motion) varied between subjects. This is not surprising because women with a history of breast cancer may or may not experience a different number of impairments (soft tissue pain[4,5], decreased shoulder girdle muscle strength[4,5], decreased tissue flexibility[6], altered resting scapular alignment[7,8], and lymphedema[4,9]) that can influence scapulohumeral coordination.[11] However, a number of clinical variables were associated with normal, more, or less relative scapular and clavicular motion. ABD ROM was the only clinical variable, across multiple scapular and clavicular rotations, that was able to classify women with a history of breast cancer into normal, more, or less relative motion during un-weighted reaching. Our findings revealed that women with less ABD demonstrated more relative scapulothoracic UR and CE during un-weighted reaching. Women with more relative CE had an average (SD) of 115.7° (51.7°) of passive ABD, while women with normal relative CE had an average of 170.6° (8.7°) and women with less relative CE had an average of 155.8° (28.0°) of passive ABD. Women with more relative upward rotation had an average (SD) of 108.7° (31.0°) of active ABD, while women with normal and less relative UR had an average (SD) of 158.2° (21.3°) and 151.8° (22.4°), respectively.

The clinical variables that were associated with impaired scapulohumeral coordination were dependent on whether the absolute position of the scapula or relative motion of the scapula was impaired. For example, shoulder ER ROM and pectoralis minor length were associated with an impairment in the anterior/posterior absolute position of the scapula (clavicular protraction) on the thorax during overhead reaching. However, isometric shoulder force production (IR during un-weighted reaching) was associated with impaired relative motion of the scapula (clavicular protraction) compared to the humerus during overhead reaching. Finally, clinical factors associated with impaired scapulohumeral coordination were dependent on which scapular or clavicular rotation was impaired. For example during un-weighted reaching, impaired relative UR was associated with active shoulder ABD ROM and % inter-limb volume difference while as previously mentioned impaired relative CP was associated with measures of muscle strength.

SUMMARY OF MODIFICATIONS

Recruitment Strategy and Eligibility Criteria Modifications

The initial plan was to recruit 75 women (25 women treated with lumpectomy and radiation, 25 women treated with mastectomy and reconstruction, and 25 women without history of breast) to participate in the study. Despite concerted efforts, subject recruitment was difficult even though a number of recruitment strategy modifications were made. Funding was obtained from the American Physical Therapy Association Oncology Section and University of Pennsylvania Transdisciplinary Research on Energetics and Cancer (TREC) Center to compensate subjects for time and travel, and support subject recruitment. Funding was initially used to support the Recruitment Outcome Assessment Resource (ROAR) within the Hospital of the University of Pennsylvania Health System (UPHS). ROAR assisted with recruitment by reviewing medical records, sending letters to potentially eligible women, and contacting women via telephone. Over an 8-month period only 2 subjects were enrolled at which time their services were discontinued. Funds were then used to support research staff within UPHS to assist with recruitment. The research assistant was responsible for reviewing physician schedules and medical records to identify potentially eligible women, and to approach women in the clinic to determine whether they would be interested in participating in the study. Over a 7-month period an additional 20 subjects were enrolled. At this time all remaining recruitment funds had been utilized. Throughout this 15 month recruitment period other strategies included recruitment from; 1) local oncologists' offices, 2) local physical therapy clinics, 3) personal contact and 4) advertising sources such as Craig's List and the Metro. These efforts led to the enrollment of 8 additional women with history of breast cancer. In total, we enrolled 30 women with history of breast cancer (10 mastectomy/reconstruction and 20 lumpectomy/radiation) in a 25-month time period. In order to have equal numbers of women with and without breast cancer, we increased the number of women without breast cancer to 30. We also modified our eligibility criteria for women with a history of breast cancer. The initial plan was to recruit women 30-70 years of age who were 1 to 3 years post-surgery. The age range was modified to 30 – 75 years and time since surgery was modified to 1 to 5 years.

A total of 134 women with a history of breast cancer were assessed for eligibility for this dissertation. A total of 39 women did not meet the inclusion/exclusion criteria, and 65 women declined to participate.   Reasons for women not wishing to participate included already being enrolled in a number of research studies, too many medical appointments, and the distance from their home to our research lab. A number of women commented they would have been interested in participating if testing could have been completed at the same location and time of their medical appointment. This was not possible because the equipment used in this dissertation to measure shoulder complex motion and coordination was not portable.

Subjects Modification

A total of 60 women participated in the study (10 mastectomy and reconstruction, 20 lumpectomy and radiation, and 30 without history of breast cancer). As previously stated, the initial plan was to enroll 25 women treated with lumpectomy and 25 women treated with mastectomy and reconstruction. Our inability to enroll the 50 women with history of breast cancer caused us to modify the statistical analysis in Chapter 2. Because an equal number of women with and without a history of breast cancer participated in the study, statistical analyses were performed to determine whether differences in ST and GH motion existed between women with and without a history of breast cancer during overhead reaching and combing hair tasks. In order to determine the effect that different breast cancer treatments (lumpectomy and radiation, and mastectomy with breast reconstruction) have on ST and GH motion (Aim 1a and 1b), we chose to perform the statistical analyses using data from an equal number (10 per group) of women treated with mastectomy/reconstruction, lumpectomy/radiation, and women without a history of breast cancer within the same age range (30-50 years or 50+ years) and BMI (normal, overweight, obese) category. Reducing our sample size resulted in low statistical power (power $< .49$ for two group comparison and power $< .39$ for three group comparison). However, we found small group differences in ST and GH motion between groups. The largest group mean difference for ST and GH motion was 3.8° of ST posterior tilt and 8.2° of GH adduction, respectively. Even if we were able to recruit enough subjects to achieve power of .80, these differences have questionable meaningfulness because they fail to exceed minimal detectable change 95% ($MDC_{95\%}$) values established in our lab on a separate group of 19 healthy subjects [13 females; 24.5 ± 3.9 years]. The $MDC_{95\%}$

values for ST posterior and GH adduction from a separate study were as high as 4.4° and 8.6°, respectively.

Modification to Definition of Impaired Shoulder Motion and Coordination

In order to classify women with breast cancer as has having impaired scapulohumeral coordination, our initial plan was to divide the angle-angle and relative motion graphs into 4 phases of movement: 0%-24%, 25%-50%, 51%-75%, and 76%-100%. Women were to be considered to have impaired scapulohumeral coordination if a single rotation's movement patterns fell outside the $MDCB_{95\%}$ for at least 2 of the 4 entire phases, or at least 2 rotations fell outside the $MDCB_{95\%}$ for at least 1 entire phase. However, it became apparent that if this definition was used, a woman could have been classified as having normal motion even if one of her rotation patterns fell outside the $MDCB_{95\%}$ from 5% -24%, 25%-50%, and 51%-70% of the movement. With this scenario, a woman would have been classified has having normal coordination since her movement pattern would have only fell outside of the $MDCB_{95\%}$ for only 1 entire phase (25-50%). Therefore, due to the novelty of using MDCBs to classify movement patterns, we decided to use a more liberal approach to our classification system. We considered a woman with history of breast cancer as having impaired scapulohumeral coordination if her curve fell outside the $MDCB_{95\%}$ for greater than 10% of the movement during the raising or lowering phases of arm movement. This decision was based on the fact that the prediction bands used to classify a movement pattern were based on the 95% confidence interval associated with minimal detectable change values. Using this approach allowed us to state, with 95% confidence that a true difference existed between movement patterns of a woman with a history of breast cancer and women without a history of breast cancer at the particular data point(s) where the women with breast cancer's curve fell outside of the prediction band. The rationale for selecting 10 data points outside of the prediction band as the cut point for classifying a movement pattern as being impaired was our intent to reduce the risk of type I error.

Our initial plan was to simply classify women as having normal or impaired scapulohumeral coordination. Once again it became apparent that more than one type of impaired scapulohumeral coordination pattern could occur. It was noted that some motion curves from women with a history of breast cancer fell above the upper boundary of the prediction band while others fell below the lower boundary of the prediction band. This information was felt to be of value for investigating the association between clinical factors and impaired scapulohumeral coordination so we decided to classify women as having normal (curve fell within $MDCB_{95\%}$), more (curve fell outside the upper limit of the $MDCB_{95\%}$), or less (curve fell outside the lower limit of the $MDCB_{95\%}$) motion.

Statistical Analysis Modification

The initial plan was to use binary logistic regression to identify clinical factors associated with impaired scapulohumeral coordination. However, with the change in the approach to classify women into three groups, (normal, more, or less motion) a binary logistic regression was no longer appropriate. Therefore, a discriminant analysis was used to determine relationships between clinical factors and whether women with history of breast cancer demonstrated normal, more, or less motion. Discriminant analysis is similar to logistic regression in that discriminant analysis can be used to assess the relationship between multiple independent variables and a categorical variable. While the dependent variable with binary logistic regression can only have two levels, the dependent variable in discriminant analysis can have multiple levels.

LIMITATIONS AND FUTURE STUDIES

An electromagnetic device (Liberty™, Polhemus, Colchester, Vermont) was used to collect continuous kinematic data of the scapula and humerus. This approach required sensors to be secured to the subjects skin. Surface sensors have been shown to be accurate for measuring GH and ST motion.[12,13] However, measurement error may occur secondary to skin motion artifact and/or difficulty palpating bony landmarks, which is an important step in the digitization process. A larger amount of measurement error has been found in individuals with a body mass index greater than 25.[12] It should be noted that 60% of the women with a history of breast cancer had a BMI in excess of 25.

The functional tasks that women were asked to perform were overhead reaching, weighted (0.9 kg) overhead reaching, and hair combing. These tasks place fairly low demands on the shoulder complex since they are not performed at end ranges of motion and do not require significant force to complete. Additionally, only 5 repetitions of each task were performed. The effect that higher demanding tasks and/or a greater number of repetitions might have on scapulothoracic and glenohumeral motion is worthy of further investigation.

In order to determine the effect that breast cancer treatments (lumpectomy and radiation, and mastectomy with breast reconstruction) have on shoulder complex motion and coordination the kinematic data from the affected sides of women with history of breast cancer (n = 30) were compared to age and BMI matched women without a history of breast cancer (n = 30). Age and BMI may be confounding factors when investigating differences in shoulder complex motion and coordination due to their association with shoulder complex kinematic variables. In this dissertation, there were significant correlations between age and resting position of the humerus, and between BMI and resting position of the humerus and scapula (Table 1). There were also significant correlations between BMI and ST and GH motion at the maximum humeral elevation angle that women achieved during the un-weighted reaching task (Table 1). The maximum humeral elevation angles that women achieved during un-weighted reaching were inversely associated with age supporting the notion that range of motion declines as women age (Table 1). It should also be noted that there was a significant correlation between age and BMI (r = .31), indicating that being older was associated with a higher BMI.

Although women in this dissertation were matched by age and BMI, assessing the differences in kinematic data between the affected and unaffected sides of women with a history of breast cancer and left and right sides of women without a history of breast cancer would be important to clearly show changes in motion and coordination of the shoulder complex after treatment for breast cancer. Comparing these differences between sides would be less affected by age or soft tissue artifact, since these factors would affect both sides in a similar way.[14] However, it should be noted that comparing unilateral shoulder complex motion between groups of subjects is common amongst shoulder research studies.[14-18]

In Chapter 2, we performed statistical analyses using data from an equal number of women within each group (10 per group) because of the unequal number of women treated with mastectomy/reconstruction (n = 10), lumpectomy/radiation (n = 20), and women without a history of breast cancer (n = 30). Subjects in the lumpectomy/ radiation and control group were selected to ensure that comparison was made within the same age range (30-50 years or 50+ years) and BMI category (normal, overweight, obese). Although the effect of hand dominance on scapular kinematics is contradictory[19-23], it should be noted that we attempted to match women treated with lumpectomy/radiation and women treated with mastectomy/reconstruction by whether the affected side was the dominant or non-dominant side. Of the 10 women, 6 were matched by whether the affected side was the dominant or non-dominant side.

A potential limitation of this study was the method by which prediction bands were calculated. Prediction bands used in this dissertation were based on minimal detectable change 95% ($MDCB_{95\%}$). $MDCB_{95\%}$ may underestimate the variability in normal movement thereby reducing the “coverage probability” of the band, which may have led to women with history of breast cancer being falsely classified has having impaired coordination.[24] Other methods such as ±1 standard deviations, ±1.7 standard deviations, and Bootstrap have been used to capture movement variability.[24, 25]

Another limitation of this study was that not all clinical factors that may influence scapulohumeral coordination were assessed. For example, we did not measure serratus anterior or trapezius muscle strength. These muscles have been shown to play an important role in the production and control of scapular upward rotation.[26] Other muscle performance measures such as endurance or electromyography activity were not included in this dissertation as well. Future studies should consider scapulothoracic muscle strength measures along with other measures of shoulder muscle performance.

Finally, the measure of pectoralis major flexibility used in this dissertation was based on a computer simulation model and the validity of the measure has yet to be supported.[27] Women with history of breast cancer may experience decreased pectoralis major flexibility due to pectoralis muscle trauma that may occur from surgery. A window may be made in the pectoralis muscle and underlying rib to access circulation during a free flap breast reconstruction procedure, or the pectoralis major may be used to create a submuscular pouch during a breast implant reconstruction procedure.[27] Impaired pectoralis major flexibility may be due to women limiting arm motion secondary to pain or fear of complications and resultant protective posturing.[28] Additionally, radiation therapy has been shown to alter collagen synthesis[29-31], and cause soft tissue fibrosis affecting the flexibility of tissues within the radiation field contributing to impaired motion.[31-33] A valid and reliable clinical measure of pectoralis major flexibility would be a valuable assessment tool for the breast cancer population.

IMPLICATIONS FOR REHABILITATION

Rehabilitation professionals routinely include assessment of shoulder ABD ROM as part of their clinical examination. Findings from these studies show that less ABD ROM is associated with more relative CE and UR during overhead reaching. This suggests that women who demonstrate less shoulder ABD ROM use compensatory shoulder girdle movement strategies during overhead reaching. Increasing the amount of CE and UR may increase the overall amount of arm elevation in order to position the hand in space to perform functional activities. Another relevant finding is that clinical measures of pectoralis minor length were associated with impaired CP during overhead reaching. This highlights the importance of including measures of flexibility when evaluating women with a history of breast cancer. Understanding that measures of shoulder ROM and flexibility are associated with specific patterns of impaired scapulohumeral coordination will allow clinicians to design interventions aimed at restoring normal scapulohumeral coordination. It is our hope that this will, in turn, help to maximize functional abilities and reduce the risk of shoulder pain and dysfunction in women with a history of breast cancer.

SUMMARY

Previous studies have shown that women with history of breast cancer demonstrate impaired scapulothoracic motion post-operatively.[14-18] However, significant differences in scapulothoracic motion between women with and without a history of breast cancer during a series of functional tasks were not found in this dissertation. Results of this dissertation did show that the majority of women with a history of breast cancer demonstrate impaired scapulohumeral coordination with respect to the absolute position of the scapula and relative motion of the scapula with respect to the humerus. However, which scapular or clavicular rotation was impaired (i.e. CP, scapular UR, etc) and direction of impairment (i.e. more or less motion) varied between subjects. This is not surprising since women with a history of breast cancer may or may not experience a different number of impairments (soft tissue pain[4,5], decreased shoulder girdle muscle strength[4,5], decreased tissue flexibility[6], altered resting scapular alignment[7,8], and lymphedema[4,9]) that can influence scapulohumeral coordination.[11] The impairments or clinical factors that were associated with impaired scapulohumeral coordination were dependent on whether the absolute position of the scapula or relative motion of the scapula was impaired along with which scapular or clavicular rotation was impaired. The results of this dissertation highlight impairments to be screened for and addressed by rehabilitation professionals in order to restore typical shoulder complex coordination. Both are important steps towards reducing the risk for developing musculoskeletal shoulder pathologies, reducing disability, and maximizing HRQoL.

Table 1: Pearson correlation coefficients for the relationship between age and body mass index and humeral and scapular kinematic variables.

Kinematic Rotation		Resting Position		Maximum Angle during Un-weighted Reaching		Range of Motion during Un-weighted Reaching#	
		Age	BMI	Age	BMI	Age	BMI
HT	Ele	.38**	.69**	-.27*	-.21	-.41**	-.55**
ST	IR	.15	.20	.25	.29*	.24	.25
	UR	-.15	-.27*	-.03	-.00	.10	.25
	PT	.35**	.46**	.25	.27*	-.02	-.11
	CE	.13	.25	.14	.12	.03	-.13
	CR	-.02	.10	-.16	-.33*	-.13	-.38**
GH	Ele	.17	.44**	-.32*	-.36**	-.42**	-.62**
	Add	.29*	.37**	.37**	.57**	.21	.39**
	IR	-.27*	-.52**	0.16	0.11	.37**	.57**

ST: scapulothoracic; GH: glenohumeral; IR: internal rotation; ER: external rotation; UR: upward rotation; PT: posterior tilt; CE: clavicular elevation; CR: clavicular retraction; Elv: elevation; Add: adduction; LR: lumpectomy/radiation; MR: mastectomy/reconstruction

- maximum – resting; * - significant at .05; ** - significant at .01

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Vita

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